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# PRSEUS Pressure Cube Test Data and Response

*Andrew E. Lovejoy  
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May 2013

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# ERRATA

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Page 2, next to last line, the phrase that reads "Frames are spaced at 20.0 inches" should read "Frames are spaced at 24.0 inches".

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## Introduction

In an effort to increase the fuel efficiency of commercial aircraft, numerous configuration concepts have been developed. One such concept is the hybrid wing body (HWB) shown in Fig. 1, which was the initial focus of NASA's Environmentally Responsible Aviation (ERA) Program. The HWB design combines features of a flying wing with features of conventional transport aircraft, a configuration that has the advantage of simultaneously increasing both fuel efficiency and payload.<sup>1,2</sup> Early in the formulation of the HWB concept, it was realized that conventional structural configurations of the time limited the potential design space for lightweight primary structure. Therefore, the conventional pressurized cabin structure was abandoned with the expectation that future structural concepts would be developed that were capable of sustaining the anticipated HWB loads.<sup>2</sup> As a result, initial HWB research focused on the aerodynamic, stability and control issues (flying characteristics), which included wind tunnel tests at NASA Langley Research Center (LaRC). While later studies have continued to address HWB flying characteristics, including noise and propulsion issues, recent years have seen an increased focus on the structural performance of the HWB.<sup>3-8</sup> The key structural challenge of a HWB airframe is the ability to create a cost and weight efficient, non-circular, pressurized shell. The fuselage of a HWB aircraft must meet the overpressure case of 2P, 18.4 psi, where 1P is defined at limit load as 9.2 psi. Conventional round fuselage sections react cabin pressure by hoop tension. However, the structural configuration of the HWB subjects the majority of the structural panels to bi-axial, in-plane loads in addition to the internal cabin pressure (Fig. 2). Therefore, the design and sizing of these nearly flat pressurized panels (identified by the shaded region in Fig. 3) requires more thorough examination and analysis than conventional transport aircraft components that have traditional and less complex load paths. To address this issue, while keeping HWB structural weights low, extensive use of advanced composite materials is made that results in architectures that are appreciably lighter than comparable aluminum designs. This report presents the test data and preliminary conclusions for a pressurized cube test article that is part of the building block approach used for HWB development.

## PRSEUS concept

Several sizing and optimization studies have been conducted on HWB-like structures.<sup>3, 4, 6, 7</sup> Of particular importance is the response of the non-circular HWB structure subjected to internal pressure, where double bending curvature (center and edges of the panel bending in opposite directions) is experienced by the pressurized panel that results in large local stresses that drive the panel design. This phenomenon is discussed in Refs. 3 and 7, and emphasizes the potential inefficiency of a uniform panel design unless the structural concept is highly efficient. One structural concept that shows great promise for application to a HWB center section is the Pultruded Rod Stitched Efficient Unitized Structure (PRSEUS)<sup>9</sup> developed by the Boeing Company. PRSEUS is an integral structural concept whereby skins, frames, stringers and tear straps are all stitched together, then infused and cured in an out-of-autoclave process.<sup>9</sup> The concept has evolved out of stitching technology development from several NASA-Boeing and AFRL-Boeing programs beginning in the 1990's.<sup>5, 10-13</sup> An expanded view of a PRSEUS stiffener intersection is shown in Fig. 4. The key to the PRSEUS concept is the pre-cured, pultruded rod that is contained within the stringer wrap plies and which passes through the frames, providing an uninterrupted load path. At the same time, the full depth frame stiffener is also continuous, except for the key-hole through which the stringer passes, providing an uninterrupted load path in the direction perpendicular to the stringer. These efficient structural stiffening members provide the majority of the panel stiffness, permitting the use of minimum skin thickness for many applications.

PRSEUS uses dry warp-knit fabric materials stitched together to create a preform of the full structural panel, so that all materials can be co-cured with minimal use of inner moldline tooling. Skins, flanges, and webs comprise layers of graphite material forms that are pre-knitted into multi-ply stacks of Hercules,

Inc. AS4 fibers. Multiple stacks of the warp-knit material are used to build up the desired part thickness and configuration. In order to maintain the panel geometry during fabrication, frames and stringers are placed in a stitching tool, and then the skin stack(s) are placed in the stitching tool to prepare for stitching of the assembly. The assembly is stitched together using Vectran thread, then the assembly is moved to a curing tool for resin infusion and consolidation in an oven using Boeing's Controlled Atmospheric Pressure Resin Infusion (CAPRI) process.<sup>9, 14</sup> Since the stiffener flanges are stitched to the skin, no mechanical fasteners are used for joining the assembly structural elements. Stringers, the stiffeners running in the HWB axial direction, consist of AS4 carbon fiber webs that overwrap a bulb-shaped, pe-cured rod of unidirectional, pultruded carbon fiber at the top of the web. Frame stiffeners are oriented along the spanwise direction, and are foam filled blades. The pultruded rods currently used in PRSEUS construction are Toray unidirectional T800 fiber with a 3900-2B resin, and currently, the frames are filled with Rohacell foam. The warp-knit stacks that are currently used in the PRSEUS skin and stiffeners make use of a (44/44/12) fiber architecture, in terms of an area weight percentage of (0/±45/90) degree plies, with a nominal stack thickness of 0.052 inches. The resin system currently used to infuse the PRSEUS assembly is HexFlow VRM 34.<sup>9</sup> Lastly, in the current HWB design, the 44% 0-degree orientation of the fuselage skin is parallel to the frames in the aircraft span-wise direction.

## **Building Block Approach**

Under the HWB structural development program, a building block approach has been used to design, analyze, build and test structural components as depicted in Fig. 5. The first pressurized PRSEUS structure was a flat panel, which is identified as the internal pressure box in the figure. This pressure panel fit into the sub-component testing portion of the Technology Readiness Level (TRL) 4 development effort. It was designed, analyzed and fabricated by Boeing,<sup>14</sup> and it was tested at NASA LaRC. The pressure panel demonstrated the pressure loading capability of minimum gauge PRSEUS panels, where the panel withstood the 2P overpressure load both without and with barely visible impact damage (BVID) imparted on a stringer, with initial failure at a pressure of 28.44 psi with BVID present.<sup>15</sup> As a next step in the building block approach, the behavior of a cube assembly made from integral PRSEUS panels that is subjected to pressure loading was examined. This test article is identified in Fig. 5 as the Pressure Cube, and it is the focus of this report. The pressure cube is an intermediate test article in the building block plan meant to reduce risk in the TRL 5 large-scale test, shown as the last step in the figure, by demonstrating PRSEUS assembly joint concepts under 2P loading. Again, this activity is a joint effort between NASA and Boeing, where Boeing completed design, analysis, manufacturing, and assembly of the test article, and NASA conducted pressure testing at LaRC's Combined Loads Test Systems (COLTS)<sup>16</sup> facility, and provided analysis and post-test correlation.

## **Pressure Cube Design**

The PRSEUS pressure cube, shown in Fig. 6, consists of six composite PRSEUS panels assembled together using aluminum fittings and a new stitched integral cap joint concept. Using the HWB as the baseline (Fig. 1), the pressure cube is designed such that it represents a region of the HWB pressurized fuselage section (Fig. 4) incorporating the crown skin, two side ribs, two side bulkheads, and a pressurized floor section as shown in Fig. 6. The crown panel is representative of the upper cover panel of the baseline aircraft in the pressure cabin region. The sides of the pressure cube are two pairs of opposing panels, arranged symmetrically, that represent rib and bulkhead panel regions. The rib and bulkhead panels are representative of the outer cabin pressure-carrying ribs and the rear pressure bulkhead of the baseline aircraft, respectively. With the exception of edge build-ups and integral caps described subsequently, all panels used in the pressure cube have the same design as the previously tested pressure panel. Frames are spaced at 20.0 inches, stringers are spaced at 6.0 inches, and with the exception of the floor, the skin is minimum gauge with a nominal thickness of 0.052 inches. The floor panel is not strictly

representative of the baseline aircraft because of the required access door and instrumentation pass-through. However, for convenience, the floor was designed to use available panel tooling, so that the stiffener spacing is identical to the remainder of the cube, but the skin thickness is significantly greater, and pad-ups have been added around the cutouts. Stringer and frame cross-sections are shown in Fig. 7, with nominal stringer and frame heights, measured from the outer mold line, of 1.49 and 6.0 inches, respectively.

Stitched T-shaped integral caps are manufactured into the panels to reduce the complexity and number of metallic fittings required to assemble the panels together. The integral cap joint design is the primary focus of the pressure cube risk reduction test article. As the first test specimen where PRSEUS panels have been joined together to create 90-degree corners, the primary purpose of the pressure cube test was to verify that the joint concept could hold the adjusted 2P load case that would be scaled up to account for the subscale cube dimensions. Integral cap members are incorporated around all four edges of the crown panel to provide a means of attaching the cube side panels (Fig. 6). The rib panels incorporate integral flanges to provide a means of attachment to the bulkhead panels. The bulkhead panels have only one cap at the lower end where they interface with the floor panel. A key feature of the pressure cube design is that there are few fasteners protruding through the outer mold line of the panel that is exposed to the airstream.

## **Pressure Cube Testing**

The pressure cube was tested in the NASA LaRC COLTS facility in August of 2011. Preliminary tests were completed to perform instrumentation checks, followed by tests of the pristine pressure cube, and then the pressure cube was impacted with BVID and pressurized to failure. This section describes the test set-up and test procedure, and concludes by presenting the test data for all applied pressure loadings.

### **Test Set-up**

The test set-up for the pressure cube is shown in Fig. 8. The crown, one rib, one bulkhead and the floor were painted with flat white-gray paint on the outer mold line (OML). The remaining rib and bulkhead were painted with a white speckle pattern to be used with a video digital image correlation system,<sup>17</sup> VIC-3D<sup>18</sup> (hereafter referred to as VIC). The pressure cube was instrumented with 11 direct current displacement transducers (DCDTs) and 168 strain gages. The locations of all DCDTs and strain gages are described in Tables 1 and 2, respectively. For the strain gage designations, the terminology is as follows: A indicates OML, B indicates inner mold line (IML), S indicates skin, W indicates web and F indicates flange. The locations of the DCDTs with respect to the cube are shown in Fig. 9, where the cube has been unfolded, with the floor removed for clarity. In the figure, the relationship between the panels on which the VIC systems were used and the remaining panels is shown, with the arrows indicating mating edges of the cube. Similarly, the general locations of the strain gages for each side of the cube are shown in Figures 10 – 15. In the figures, each edge of the panel is identified by the mating panel to which that edge is attached (e.g., an edge labeled as "crown" indicates that edge is attached to the crown panel). VIC was used to monitor displacements and strains on the speckled rib and bulkhead panels. Two VIC systems were used for global measurements, one for the rib and one for the bulkhead. A third VIC system was added in the final load-to-failure test to monitor a local region on the rib in the vicinity of BVID. Additionally, the interior of the pressure cube was monitored using video cameras with light-emitting diode (LED) lighting, and several cameras provided video monitoring of the exterior of the pressure cube. Lastly, acoustic emission (AE) sensors were installed on all of the panels except for the floor. Several of the AE sensors can be seen in Fig. 8, and their pattern and numbering is shown in Fig. 16. Full details associated with the AE portion of the testing can be found in Ref. 19.

Due to the danger involved with pressurized tests, the cube was tested in the COLTS pressure chamber. This chamber is an enclosed volume that can contain the explosive failure of a pressurized test article up to the size of a 45-foot long fuselage section. Output signals from DCDTs, strain gages, VIC computers and AE sensors on were monitored in the COLTS control room.

## **Test Procedure**

The pressure cube was subjected to several pressure loads to various levels in a pristine condition, and pressure loaded to failure with BVID imparted to the exterior of the cube at a rib integral cap web location. Design pressures for the cube are designated as 1P, which represents the normal operating pressure of 9.2 psi, and 2P, which represents the 18.4 psi maximum overpressure condition. In the pristine condition, two check-out tests were conducted with the pressure ramped up to 4.6 psi (0.5P). These check-out tests were used to verify proper operation of all data acquisition systems and the pressure control system. The pristine cube was then pressurized up to 1P and then unpressurized. During the 1P testing, vibration surveys were performed to provide data used to validate finite element models to enable accurate prediction of pressurized PRSEUS panel dynamics.<sup>20</sup> The vibration surveys were made at zero pressure and 1P, and at 6 steady-state pressure holds through the loading up to 1P. The final pristine cube test increased the pressure up to 20.15 psi (2.2P) prior to being unpressurized. The purpose of the 2.2P load is to ensure that no failure will occur for the overpressure condition, but with an additional margin of 10% included. At the conclusion of the pristine cube tests, the cube was examined using ultrasonic NDI and the BVID was introduced. The cube was turned on its side, NDI was performed, then BVID was imparted, using a drop weight impactor, to the speckled rib integral cap web that attached the rib to the speckled bulkhead, as shown in Figure 17. The location of the BVID with respect to the integral cap web is shown in Figure 18, and its location on the cube is shown in Figure 19. The BVID was imparted with an impact energy of 100 ft-lbs using a 1-inch spherical impactor. Figure 20 shows the impact location surface before and after introducing the BVID. Additional NDI was performed in the vicinity of the BVID with the cube on its side prior to being rotated back to the test position and reinstalling DCDTs. The pressure cube was then pressurized until catastrophic failure occurred. NDI was performed on what remained of the cube after the catastrophic failure.

## **Test Data**

As described in the test set-up section, data was collected on the pressure cube using DCDTs, strain gages and VIC. Data was collected for all test loads; the two 0.5P check-out tests, the 1P test, the 2.2P test and the test to failure. Plots of all DCDT and strain gage test data for all five of the test loads is provided for reference in Appendices A through E. The two check-out tests were uneventful, as was expected since the load level was low. Data for the two check-out tests is provided in Appendices A and B. The third loading took the pressure cube to 1P, and the maximum center-of-panel displacement measured by the DCDTs for the crown, rib and bulkhead were 0.042, 0.0098 and 0.19 inches, respectively. The only strain gage that showed other than smooth response was SG95AW, as shown in Figure 21. As described in Table 2, this gage is above a keyhole, and this slope discontinuity could be attributed to cracking or failure of the resin that collects between the stringer and integral cap web during infusion. The stringers are expected to pass through keyholes without any connection, but resin collects in the keyhole region providing a weak connection between the stringer and structure in which the keyhole exists (i.e. frame, integral cap). Therefore, testing showed no unexpected response up to 1P. Complete data for the 1P loading condition is presented in Appendix C.

The cube was then loaded to 2.2P. No catastrophic failure or visible damage resulted from the 2.2P loading. However, test data indicates that nonvisible damage did occur. DCDT6 showed significant slope discontinuities in the displacement-load relationship at about 16 and 19 psi, as shown in Figure 22. The

strain gage results in the vicinity of DCDT6 show slope discontinuities at the same pressure levels, as shown in Figures 23-25. Also, similar behavior is seen at crown and rib gages in the mirrored locations, as shown in Figures 26-28. Numerous other gages showed mildly nonlinear behavior and minor slope discontinuities in strain level, but they were not as severe as those shown in the figures. The ultrasonic NDI performed after the completion of this load level (see Ref. 21) indicated that delaminations developed in the vicinity of the crown integral caps attached to the ribs, as shown in Figure 29, which is consistent with the DCDT and strain gage data that was presented. Therefore, no visible damage was observed, but there was internal, nonvisible damage after the 2.2P load. Complete data for the 2.2P loading condition is presented in Appendix D.

Lastly, the pressure cube was subjected to BVID and loaded to catastrophic failure. Throughout the loading, many indications of local damage were observed by the DCDTs and strain gages, but no visible damage was observed, and catastrophic failure did not occur until 48 psi. Complete data for the loading to catastrophic failure is presented in Appendix E, and results of interest are presented here. Displacement plots for selected DCDTs are shown in Figures 30-33, and are for the panel center displacements and DCDT6 that was located at one of the crown delaminations. The VIC-measured displacements at several pressure levels are shown in Figures 34-39 for the rib and bulkhead. VIC-measured displacements just prior to catastrophic failure are shown in Figures 40 and 41 for the rib and bulkhead, respectively, with a close-up of the BVID region shown in Figure 42. No effect of the BVID presence can be seen in Figure 42. A large number of strain gages exhibited nonlinear behavior or small slope discontinuities in the strain level, but the majority of these recorded very small strain levels, in many cases on the order of a few hundred microstrain. The maximum strains observed were on the bulkhead frame in the vicinity of a keyhole and on the cap, as shown in Figures 43-44. In the vicinity of the keyhole, the strain exhibited instantaneous slope discontinuity, increasing from  $-4,000 \mu\epsilon$  to  $-12,000 \mu\epsilon$  at 45.7 psi for SG83BW, and from  $-5,000 \mu\epsilon$  to  $-12,000 \mu\epsilon$  from 47 to 48 psi for SG75BW. However, at the keyhole, local failures would be expected due to the stress concentration, but these local failures do not necessarily lead to catastrophic failure. The maximum strains in the frame caps were approximately  $-10,000 \mu\epsilon$  as seen in Figures 45-46. Figures 47-50 show the response of the strain gages in the vicinity of the two delamination locations on the crown panel, where continued delamination growth can be identified as indicated by the slope discontinuities in strain recorded by the gages. Nonlinear behavior of the skin is demonstrated by the strain gage plots shown in Figures 51 and 52, for gages located near the center of the gray bulkhead. However, the strains for these gages are well within the specified allowable values, as are almost all of the strains recorded by the gages. Finally, the pressure cube after failure is shown in Figure 53. In addition to the composite failure, failure in the aluminum connection between the crown panel and speckled rib frames was found, as shown in Figure 54. Frame buckling of the speckled rib frame attached to the failed aluminum connection is observed as shown in Figure 55.

## Discussion and Conclusions

This document presents the complete displacement and strain gage data for the PRSEUS pressure cube test conducted at the NASA LaRC COLTS test facility. For the two checkout loading conditions, up to 0.5P pressure, no abnormal behavior of the cube was observed. In the third loading condition, which was pressurized up to 1P, normal and smooth response was observed for all displacements and strains except for strain gage SG95AW, where several slope discontinuities in strain were seen, but strain levels remained less than 720 microstrain. The cube was pressurized a fourth time up to a load level of 2.2P. During this fourth loading, displacement and strain slope discontinuities were observed. Subsequent NDE identified delaminations in the vicinity of the crown integral caps that connect the crown to the ribs. The final loading was to catastrophic failure after BVID was introduced into the integral cap attaching the speckled rib to the speckled bulkhead. Numerous nonlinear strain responses, including slope discontinuities in strain, were observed. However, the majority of the strains recorded remained within



the allowable strain levels. Also, no effect of the BVID presence was observed in the VIC data or strain gage data. The initial most likely final failure sequence is speculative due to the fact that the failure occurred instantaneously and there were no indications by the instrumentation from which to draw clear conclusions. However, catastrophic first failure of the frame fitting is supported by the analysis, test data and observed failure modes.<sup>22</sup> A possible future effort could entail examination of the data presented herein in conjunction with the AE and NDE data presented in References 19 and 21, respectively, to provide better insight into the failure sequence of the pressure cube.

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## Tables

Table 1: Descriptions of cube DCDT locations.

| DCDT | Panel         | Description                                                               |
|------|---------------|---------------------------------------------------------------------------|
| 1    | Crown         | Centered on frame, centered over integral cap                             |
| 2    | Crown         | Centered on frame, centered over integral cap                             |
| 3    | Crown         | Centered on frame, centered over integral cap                             |
| 4    | Crown         | Centered on frame, centered over integral cap                             |
| 5    | Crown         | Centered on frame, centered over center stringer                          |
| 6    | Crown         | Centered on integral cap, center of crown panel width                     |
| 7    | Crown         | Geometric center of panel                                                 |
| 8    | Crown         | Centered on center stringer, centered between frame and integral cap      |
| 9    | Crown         | Centered on center stringer, adjacent to crown panel edge                 |
| 10   | Gray Bulkhead | Centered between crown and floor panels, centered on bulkhead panel width |
| 11   | Gray Rib      | Centered between crown and floor panels, centered on rib panel width      |

Table 2: Descriptions of cube strain gage locations.

| Strain Gage | Panel | Description                                                                                                               |
|-------------|-------|---------------------------------------------------------------------------------------------------------------------------|
| SG1AC       | Floor | Centered on frame adjacent to gray bulkhead, top of frame cap, parallel to frame direction                                |
| SG1BS       | Floor | Centered on frame adjacent to gray bulkhead, inside skin surface, parallel to frame direction                             |
| SG2AC       | Floor | Centered on frame adjacent to speckled bulkhead, top of frame cap, parallel to frame direction                            |
| SG2BS       | Floor | Centered on frame adjacent to speckled bulkhead, inside skin surface, parallel to frame direction                         |
| SG3AC       | Floor | Centered on stringer adjacent to speckled rib, top of stringer cap, parallel to stringer direction                        |
| SG3BS       | Floor | Centered on stringer adjacent to speckled rib, inside skin surface, parallel to stringer direction                        |
| SG4AC       | Floor | Centered on stringer adjacent to gray rib, top of stringer cap, parallel to stringer direction                            |
| SG4BS       | Floor | Centered on stringer adjacent to gray rib, inside skin surface, parallel to stringer direction                            |
| SG5BW       | Floor | Centered on stringer adjacent to gray rib, outside surface of stringer web, parallel to stringer direction                |
| SG6BW       | Floor | Centered on stringer adjacent to gray rib, inside surface of stringer web, parallel to stringer direction                 |
| SG7BW       | Floor | Centered on stringer adjacent to speckled rib, outside surface of stringer web, parallel to stringer direction            |
| SG8BW       | Floor | Centered on stringer adjacent to speckled rib, inside surface of stringer web, parallel to stringer direction             |
| SG9AS       | Crown | Centered between bulkheads, outer skin adjacent to first stringer flange on gray rib side, parallel to stringer direction |
| SG9BS       | Crown | Centered between bulkheads, inner skin adjacent to first stringer flange on gray rib side, parallel to stringer direction |
| SG10AS      | Crown | Centered between bulkheads, outer skin adjacent to first stringer flange on gray rib side, parallel to frame direction    |
| SG10BS      | Crown | Centered between bulkheads, inner skin adjacent to first stringer flange on gray rib side, parallel to frame direction    |

| Strain Gage | Panel | Description                                                                                                                                                 |
|-------------|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
| SG11BW      | Crown | Centered between bulkheads, top of stringer adjacent to gray rib, web outer surface, parallel to stringer direction                                         |
| SG12BW      | Crown | Centered between bulkheads, top of stringer adjacent to gray rib, web inner surface, parallel to stringer direction                                         |
| SG13AS      | Crown | Centered between bulkheads, outer skin centered on bay adjacent to center stringer on gray rib side, parallel to stringer direction                         |
| SG13BS      | Crown | Centered between bulkheads, inner skin centered on bay adjacent to center stringer on gray rib side, parallel to stringer direction                         |
| SG14AS      | Crown | Centered between bulkheads, outer skin centered on bay adjacent to center stringer on gray rib side, parallel to frame direction                            |
| SG14BS      | Crown | Centered between bulkheads, inner skin centered on bay adjacent to center stringer on gray rib side, parallel to frame direction                            |
| SG15AS      | Crown | Centered between bulkheads, outer skin centered on center stringer, parallel to stringer direction                                                          |
| SG15BC      | Crown | Centered between bulkheads, top of stringer rod of center stringer, parallel to stringer direction                                                          |
| SG16AS      | Crown | Centered between bulkheads, outer skin centered on bay adjacent to center stringer on speckled rib side, parallel to stringer direction                     |
| SG16BS      | Crown | Centered between bulkheads, inner skin centered on bay adjacent to center stringer on speckled rib side, parallel to stringer direction                     |
| SG17AS      | Crown | Centered between bulkheads, outer skin centered on bay adjacent to center stringer on speckled rib side, parallel to frame direction                        |
| SG17BS      | Crown | Centered between bulkheads, inner skin centered on bay adjacent to center stringer on speckled rib side, parallel to frame direction                        |
| SG18BW      | Crown | Centered between bulkheads, top of stringer web inner surface adjacent to speckled rib, parallel to stringer direction                                      |
| SG19BW      | Crown | Centered between bulkheads, top of stringer web outer surface adjacent to speckled rib, parallel to stringer direction                                      |
| SG20AS      | Crown | Centered between bulkheads, outer skin adjacent to first stringer flange on speckled rib side, parallel to frame direction                                  |
| SG20BS      | Crown | Centered between bulkheads, inner skin adjacent to first stringer flange on speckled rib side, parallel to frame direction                                  |
| SG21AS      | Crown | Centered between bulkheads, outer skin adjacent to first stringer flange on speckled rib side, parallel to stringer direction                               |
| SG21BS      | Crown | Centered between bulkheads, inner skin adjacent to first stringer flange on speckled rib side, parallel to stringer direction                               |
| SG22AS      | Crown | Intersection corner of center stringer and frame flanges, adjacent to speckled bulkhead on gray rib side, outer skin, parallel to frame direction           |
| SG22BF      | Crown | Intersection corner of center stringer and frame flanges, adjacent to speckled bulkhead on gray rib side, inner surface, parallel to frame direction        |
| SG23AS      | Crown | Intersection corner of center stringer and frame flanges, adjacent to speckled bulkhead on speckled rib side, outer skin, parallel to stringer direction    |
| SG23BF      | Crown | Intersection corner of center stringer and frame flanges, adjacent to speckled bulkhead on speckled rib side, inner surface, parallel to stringer direction |
| SG24BW      | Crown | Centered above center stringer, top of inner web surface of frame, adjacent to speckled bulkhead, parallel to frame direction                               |
| SG25BW      | Crown | Centered above center stringer, top of outer web surface of frame, adjacent to speckled bulkhead, parallel to frame direction                               |
| SG26AS      | Crown | Intersection corner of center stringer and frame flanges, adjacent to gray bulkhead on gray rib side, outer skin, parallel to frame direction               |

| Strain Gage | Panel    | Description                                                                                                                                                        |
|-------------|----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| SG26BF      | Crown    | Intersection corner of center stringer and frame flanges, adjacent to gray bulkhead on gray rib side, inner surface, parallel to frame direction                   |
| SG27AS      | Crown    | Intersection corner of center stringer and frame flanges, adjacent to gray bulkhead on speckled rib side, outer skin, parallel to stringer direction               |
| SG27BF      | Crown    | Intersection corner of center stringer and frame flanges, adjacent to gray bulkhead on speckled rib side, inner surface, parallel to stringer direction            |
| SG28AS      | Crown    | Intersection corner of center stringer and integral cap flanges, adjacent to gray bulkhead on gray rib side, outer skin, parallel to stringer direction            |
| SG28BF      | Crown    | Intersection corner of center stringer and integral cap flanges, adjacent to gray bulkhead on gray rib side, inner surface, parallel to stringer direction         |
| SG29AS      | Crown    | Intersection corner of center stringer and integral cap flanges, adjacent to gray bulkhead on speckled rib side, outer skin, parallel to stringer direction        |
| SG29BF      | Crown    | Intersection corner of center stringer and integral cap flanges, adjacent to gray bulkhead on speckled rib side, inner surface, parallel to stringer direction     |
| SG30BW      | Crown    | Beside 3rd stringer from gray rib rod, inner web surface of frame, adjacent to gray bulkhead, parallel to frame height direction                                   |
| SG31BW      | Crown    | Centered just above 3rd stringer from gray rib, inner web surface of frame, adjacent to gray bulkhead, parallel to frame direction                                 |
| SG32BW      | Crown    | Centered above center stringer, top of inner web surface of frame, adjacent to gray bulkhead rib, parallel to frame direction                                      |
| SG33BW      | Crown    | Centered above center stringer, top of outer web surface of frame, adjacent to gray bulkhead, parallel to frame direction                                          |
| SG34AS      | Crown    | Intersection corner of center stringer and integral cap flanges, adjacent to speckled bulkhead on gray rib side, outer skin, parallel to stringer direction        |
| SG34BF      | Crown    | Intersection corner of center stringer and integral cap flanges, adjacent to speckled bulkhead on gray rib side, inner surface, parallel to stringer direction     |
| SG35AS      | Crown    | Intersection corner of center stringer and integral cap flanges, adjacent to speckled bulkhead on speckled rib side, outer skin, parallel to stringer direction    |
| SG35BF      | Crown    | Intersection corner of center stringer and integral cap flanges, adjacent to speckled bulkhead on speckled rib side, inner surface, parallel to stringer direction |
| SG36BW      | Gray rib | Centered between bulkheads, on stringer adjacent to crown panel, top of web outer surface, parallel to stringer direction                                          |
| SG37BW      | Gray rib | Centered between bulkheads, on stringer adjacent to crown panel, top of web inner surface, parallel to stringer direction                                          |
| SG38AS      | Gray rib | Centered between bulkheads, outer skin centered on bay adjacent to center stringer on crown panel side, parallel to frame direction                                |
| SG38BS      | Gray rib | Centered between bulkheads, inner skin centered on bay adjacent to center stringer on crown panel side, parallel to frame direction                                |
| SG39AS      | Gray rib | Centered between bulkheads, outer skin centered on bay adjacent to center stringer on crown panel side, parallel to stringer direction                             |
| SG39BS      | Gray rib | Centered between bulkheads, inner skin centered on bay adjacent to center stringer on crown panel side, parallel to stringer direction                             |

| Strain Gage | Panel    | Description                                                                                                                                                      |
|-------------|----------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| SG40AS      | Gray rib | Centered between bulkheads, outer skin centered on center stringer, parallel to stringer direction                                                               |
| SG40BC      | Gray rib | Centered between bulkheads, top of stringer rod of center stringer, parallel to stringer direction                                                               |
| SG41AS      | Gray rib | Centered between bulkheads, outer skin centered on bay adjacent to center stringer on floor panel side, parallel to stringer direction                           |
| SG41BS      | Gray rib | Centered between bulkheads, inner skin centered on bay adjacent to center stringer on floor panel side, parallel to stringer direction                           |
| SG42AS      | Gray rib | Centered between bulkheads, outer skin centered on bay adjacent to center stringer on floor panel side, parallel to frame direction                              |
| SG42BS      | Gray rib | Centered between bulkheads, inner skin centered on bay adjacent to center stringer on floor panel side, parallel to frame direction                              |
| SG43BW      | Gray rib | Centered between bulkheads, on stringer adjacent to crown panel, top of web outer surface, parallel to stringer direction                                        |
| SG44BW      | Gray rib | Centered between bulkheads, on stringer adjacent to crown panel, top of web inner surface, parallel to stringer direction                                        |
| SG45AS      | Gray rib | Centered between bulkheads, outer skin centered on bay adjacent to bottom stringer on floor panel side, parallel to stringer direction                           |
| SG45BS      | Gray rib | Centered between bulkheads, inner skin centered on bay adjacent to bottom stringer on floor panel side, parallel to stringer direction                           |
| SG46AS      | Gray rib | Centered between bulkheads, outer skin centered on bay adjacent to bottom stringer on floor panel side, parallel to frame direction                              |
| SG46BS      | Gray rib | Centered between bulkheads, inner skin centered on bay adjacent to bottom stringer on floor panel side, parallel to frame direction                              |
| SG47AS      | Gray rib | Intersection corner of center stringer and frame inner flanges, adjacent to speckled bulkhead on floor side, outer skin, parallel to frame direction             |
| SG47BF      | Gray rib | Intersection corner of center stringer and frame inner flanges, adjacent to speckled bulkhead on floor side, inner surface, parallel to frame direction          |
| SG48AS      | Gray rib | Intersection corner of center stringer and frame inner flanges, adjacent to speckled bulkhead on crown panel side, outer skin, parallel to stringer direction    |
| SG48BF      | Gray rib | Intersection corner of center stringer and frame inner flanges, adjacent to speckled bulkhead on crown panel side, inner surface, parallel to stringer direction |
| SG49BW      | Gray rib | Frame adjacent to speckled bulkhead, centered above stringer 4, top of web inner surface                                                                         |
| SG50BW      | Gray rib | Frame adjacent to speckled bulkhead, centered above stringer 4, top of web outer surface                                                                         |
| SG51BW      | Gray rib | Beside bottom stringer rod, inner web surface of frame, adjacent to speckled bulkhead, parallel to frame height direction                                        |
| SG52BW      | Gray rib | Centered just above bottom stringer, inner web surface of frame, adjacent to speckled bulkhead, parallel to frame direction                                      |
| SG53AS      | Gray rib | Intersection corner of center stringer and frame inner flanges, adjacent to gray bulkhead on floor side, outer skin, parallel to frame direction                 |
| SG53BF      | Gray rib | Intersection corner of center stringer and frame inner flanges, adjacent to gray bulkhead on floor side, inner surface, parallel to frame direction              |
| SG54AS      | Gray rib | Intersection corner of center stringer and frame inner flanges, adjacent to gray bulkhead on crown panel side, outer skin, parallel to stringer direction        |

| Strain Gage | Panel         | Description                                                                                                                                                  |
|-------------|---------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|
| SG54BF      | Gray rib      | Intersection corner of center stringer and frame inner flanges, adjacent to gray bulkhead on crown panel side, inner surface, parallel to stringer direction |
| SG55BW      | Gray rib      | Frame adjacent to gray bulkhead, centered above 4th stringer from bottom, top of web inner surface, parallel to frame                                        |
| SG56BW      | Gray rib      | Frame adjacent to gray bulkhead, centered above 4th stringer from bottom, top of web outer surface, parallel to frame                                        |
| SG57BW      | Gray rib      | Beside bottom stringer rod, inner web surface of frame, adjacent to gray bulkhead, parallel to frame height direction                                        |
| SG58BW      | Gray rib      | Centered just above bottom stringer, inner web surface of frame, adjacent to gray bulkhead, parallel to frame direction                                      |
| SG59AS      | Gray rib      | Centered on bottom stringer and frame, outer skin, adjacent to gray bulkhead, parallel to frame direction                                                    |
| SG59BC      | Gray rib      | Centered above bottom stringer, top of frame, adjacent to gray bulkhead, parallel to frame direction                                                         |
| SG60AS      | Gray rib      | Centered on bottom stringer and frame, outer skin, adjacent to speckled bulkhead, parallel to frame direction                                                |
| SG60BC      | Gray rib      | Centered above bottom stringer, top of frame, adjacent to speckled bulkhead, parallel to frame direction                                                     |
| SG61BW      | Gray bulkhead | Centered between ribs, top of stringer adjacent to crown panel, web outer surface, parallel to stringer direction                                            |
| SG62BW      | Gray bulkhead | Centered between ribs, top of stringer adjacent to crown panel, web inner surface, parallel to stringer direction                                            |
| SG63AS      | Gray bulkhead | Centered between ribs, outer skin centered on bay between center pair of stringers, parallel to frame direction                                              |
| SG63BS      | Gray bulkhead | Centered between ribs, inner skin centered on bay between center pair of stringers, parallel to frame direction                                              |
| SG64AS      | Gray bulkhead | Centered between ribs, outer skin centered on bay between center pair of stringers, parallel to stringer direction                                           |
| SG64BS      | Gray bulkhead | Centered between ribs, inner skin centered on bay between center pair of stringers, parallel to stringer direction                                           |
| SG65AS      | Gray bulkhead | Centered between ribs, outer skin centered on 4th stringer from bottom, parallel to stringer direction                                                       |
| SG65BC      | Gray bulkhead | Centered between ribs, top of stringer rod of 4th stringer from bottom, parallel to stringer direction                                                       |
| SG66AS      | Gray bulkhead | Centered between ribs, outer skin centered on bay adjacent to 4th stringer from bottom on floor panel side, parallel to stringer direction                   |
| SG66BS      | Gray bulkhead | Centered between ribs, inner skin centered on bay adjacent to 4th stringer from bottom on floor panel side, parallel to stringer direction                   |
| SG67AS      | Gray bulkhead | Centered between ribs, outer skin centered on bay adjacent to 4th stringer from bottom on floor panel side, parallel to frame direction                      |
| SG67BS      | Gray bulkhead | Centered between ribs, inner skin centered on bay adjacent to 4th stringer from bottom on floor panel side, parallel to frame direction                      |
| SG68BW      | Gray bulkhead | Centered between ribs, top of stringer adjacent to floor, web inner surface, parallel to stringer direction                                                  |
| SG69BW      | Gray bulkhead | Centered between ribs, top of stringer adjacent to floor, web outer surface, parallel to stringer direction                                                  |
| SG70AS      | Gray bulkhead | Centered on frame adjacent to speckled rib and 4th stringer from bottom, outer skin, parallel to frame                                                       |
| SG70BC      | Gray bulkhead | Frame adjacent to speckled rib, centered above 4th stringer from bottom, top of frame cap, parallel to frame                                                 |
| SG71BW      | Gray bulkhead | Frame adjacent to speckled rib, centered above 4th stringer from bottom, top of web inner surface, parallel to frame                                         |

| Strain Gage | Panel         | Description                                                                                                                                                          |
|-------------|---------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| SG72BW      | Gray bulkhead | Frame adjacent to speckled rib, centered above 4th stringer 4from bottom, top of web outer surface, parallel to frame                                                |
| SG73AS      | Gray bulkhead | Intersection corner of 4th stringer from bottom and frame inner flanges, adjacent to speckled rib on floor side, outer skin, parallel to frame direction             |
| SG73BF      | Gray bulkhead | Intersection corner of 4th stringer from bottom and frame inner flanges, adjacent to speckled rib on floor side, inner surface, parallel to frame direction          |
| SG74AS      | Gray bulkhead | Intersection corner of 4th stringer from bottom and frame inner flanges, adjacent to speckled rib on crown panel side, outer skin, parallel to stringer direction    |
| SG74BF      | Gray bulkhead | Intersection corner of 4th stringer from bottom and frame inner flanges, adjacent to speckled rib on crown panel side, inner surface, parallel to stringer direction |
| SG75BW      | Gray bulkhead | Beside 2nd stringer from bottom rod, inner web surface of frame, adjacent to speckled rib, parallel to frame height direction                                        |
| SG76BW      | Gray bulkhead | Centered just above 2nd stringer from bottom, inner web surface of frame, adjacent to speckled rib, parallel to frame direction                                      |
| SG77AS      | Gray bulkhead | Centered on frame adjacent to gray rib and 4th stringer from bottom, outer skin, parallel to frame                                                                   |
| SG77BC      | Gray bulkhead | Frame adjacent to gray rib, centered above 4th stringer from bottom, top of frame cap, parallel to frame                                                             |
| SG78BW      | Gray bulkhead | Frame adjacent to gray rib, centered above 4th stringer from bottom, top of web inner surface, parallel to frame                                                     |
| SG79BW      | Gray bulkhead | Frame adjacent to gray rib, centered above 4th stringer 4from bottom, top of web outer surface, parallel to frame                                                    |
| SG80AS      | Gray bulkhead | Intersection corner of 4th stringer from bottom and frame inner flanges, adjacent to gray rib on crown panel side, outer skin, parallel to stringer direction        |
| SG80BF      | Gray bulkhead | Intersection corner of 4th stringer from bottom and frame inner flanges, adjacent to gray rib on crown panel side, inner surface, parallel to stringer direction     |
| SG81AS      | Gray bulkhead | Intersection corner of 4th stringer from bottom and frame inner flanges, adjacent to gray rib on floor side, outer skin, parallel to frame direction                 |
| SG81BF      | Gray bulkhead | Intersection corner of 4th stringer from bottom and frame inner flanges, adjacent to gray rib on floor side, inner surface, parallel to frame direction              |
| SG82BW      | Gray bulkhead | Centered just above 2nd stringer from bottom, inner web surface of frame, adjacent to gray rib, parallel to frame direction                                          |
| SG83BW      | Gray bulkhead | Beside 2nd stringer from bottom rod, inner web surface of frame, adjacent to gray rib, parallel to frame height direction                                            |
| SG84AW      | Speckled rib  | Centered between bulkheads, outer cap surface at top against tangency point, parallel to frame direction                                                             |
| SG84BW      | Speckled rib  | Centered between bulkheads, inner skin surface against edge of skin, parallel to frame direction                                                                     |
| SG85AW      | Gray rib      | Centered between bulkheads, outer cap surface at top against tangency point, parallel to frame direction                                                             |
| SG85BW      | Gray rib      | Centered between bulkheads, inner skin surface against edge of skin, parallel to frame direction                                                                     |
| SG86AW      | Gray bulkhead | Centered between ribs, outer cap surface, just below stringer, parallel to stringer direction                                                                        |
| SG87AW      | Gray bulkhead | Beside center stringer, outer cap surface at top against tangency point, on speckled rib side, parallel to frame direction                                           |



| Strain Gage | Panel             | Description                                                                                                                                                          |
|-------------|-------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| SG88AW      | Gray bulkhead     | Beside center stringer, outer cap surface at top against tangency point, on gray rib side, parallel to frame direction                                               |
| SG89AW      | Gray bulkhead     | Close to center stringer below flange edge, outer cap surface at level of SG87AW, on speckled rib side, parallel to frame direction                                  |
| SG89BW      | Gray bulkhead     | Close to center stringer below flange edge, inner skin surface at edge of skin, on speckled rib side, parallel to frame direction                                    |
| SG90AW      | Speckled bulkhead | Centered between ribs, outer cap surface, just below stringer, parallel to stringer direction                                                                        |
| SG91AW      | Speckled bulkhead | Speckled bulkhead, beside center stringer, outer cap surface at top against tangency point, on speckled rib side, parallel to frame direction                        |
| SG92AW      | Speckled bulkhead | Speckled bulkhead, beside center stringer, outer cap surface at top against tangency point, on gray rib side, parallel to frame direction                            |
| SG93AW      | Speckled bulkhead | Close to center stringer below flange edge, outer cap surface at level of SG92AW, on gray rib side, parallel to frame direction                                      |
| SG93BW      | Speckled bulkhead | Close to center stringer below flange edge, inner skin surface at edge of skin, on gray rib side, parallel to frame direction                                        |
| SG94AW      | Gray bulkhead     | Close to speckled rib center stringer at flange edge, outer cap surface at level of SG96AW, on floor side, parallel to stringer direction                            |
| SG94BW      | Gray bulkhead     | Close to speckled rib center stringer at flange edge, inner skin surface at edge of skin, on floor side, parallel to stringer direction                              |
| SG95AW      | Gray bulkhead     | Gray bulkhead, adjacent to speckled rib center stringer rod, outer cap surface, parallel to frame direction                                                          |
| SG96AW      | Gray bulkhead     | Beside speckled rib center stringer, outer cap surface at side against tangency point, on floor side, parallel to stringer direction                                 |
| SG97AW      | Gray bulkhead     | Close to gray rib center stringer at flange edge, outer cap surface at level of SG96AW, on crown side, parallel to stringer direction                                |
| SG97BW      | Gray bulkhead     | Close to gray rib center stringer at flange edge, inner skin surface at edge of skin, on crown side, parallel to stringer direction                                  |
| SG98AW      | Gray bulkhead     | Gray bulkhead, adjacent to gray rib center stringer rod, outer cap surface, parallel to frame direction                                                              |
| SG99AW      | Gray bulkhead     | Beside gray rib center stringer, outer cap surface at side against tangency point, on floor side, parallel to stringer direction                                     |
| SG100BW     | Gray rib          | Beside bottom stringer rod, outer web surface of frame, adjacent to gray bulkhead, parallel to frame height direction                                                |
| SG101BW     | Gray rib          | Centered just above bottom stringer, outer web surface of frame, adjacent to gray bulkhead rib, parallel to frame direction                                          |
| SG102BF     | Gray bulkhead     | Intersection corner of 4th stringer from bottom and frame outer flanges, adjacent to speckled rib on crown panel side, inner surface, parallel to stringer direction |
| SG103BF     | Gray bulkhead     | Intersection corner of 4th stringer from bottom and frame outer flanges, adjacent to speckled rib on floor side, inner surface, parallel to frame direction          |
| SG104BF     | Gray bulkhead     | Beside 2nd stringer from bottom rod, outer web surface of frame, adjacent to gray rib, parallel to frame height direction                                            |
| SG105BF     | Gray bulkhead     | Centered just above 2nd stringer from bottom, outer web surface of frame, adjacent to gray rib, parallel to frame direction                                          |
| SG106BW     | Crown             | Beside 2nd stringer from gray rib rod, outer web surface of frame, adjacent to speckled bulkhead, parallel to frame height direction                                 |
| SG107BW     | Crown             | Centered just above 2nd stringer from gray rib, outer web surface of frame, adjacent to speckled bulkhead, parallel to frame direction                               |
| SG108BW     | Crown             | Beside 3rd stringer from gray rib rod, outer web surface of frame, adjacent to speckled bulkhead, parallel to frame height direction                                 |
| SG109BW     | Crown             | Centered just above 3rd stringer from gray rib, outer web surface of frame, adjacent to speckled bulkhead, parallel to frame direction                               |



| Strain Gage | Panel             | Description                                                                                                                                                  |
|-------------|-------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|
| SG110BF     | Gray rib          | Intersection corner of center stringer and frame outer flanges, adjacent to gray bulkhead on crown panel side, inner surface, parallel to stringer direction |
| SG111BF     | Gray rib          | Intersection corner of center stringer and frame outer flanges, adjacent to gray bulkhead on floor side, inner surface, parallel to frame direction          |
| SG113BW     | Crown             | Beside 3rd stringer from gray rib rod, inner web surface of frame, adjacent to speckled bulkhead, parallel to frame height direction                         |
| SG114BW     | Crown             | Centered just above 3rd stringer from gray rib, inner web surface of frame, adjacent to speckled bulkhead, parallel to frame direction                       |
| SG115AW     | Gray bulkhead     | Beside speckled rib center stringer, outer cap surface at side against tangency point, on crown panel side, parallel to stringer direction                   |
| SG116AW     | Gray bulkhead     | Beside gray rib center stringer, outer cap surface at side against tangency point, on crown panel side, parallel to stringer direction                       |
| SG117AW     | Gray bulkhead     | Close to center stringer below flange edge, outer cap surface at level of 88AW, on gray rib side, parallel to frame direction                                |
| SG118AW     | Speckled bulkhead | Close to center stringer beside SG93AW, outer cap surface at level of SG92AW, on gray rib side, parallel to frame direction                                  |

## Figures



Figure 1. Typical HWB aircraft concept.

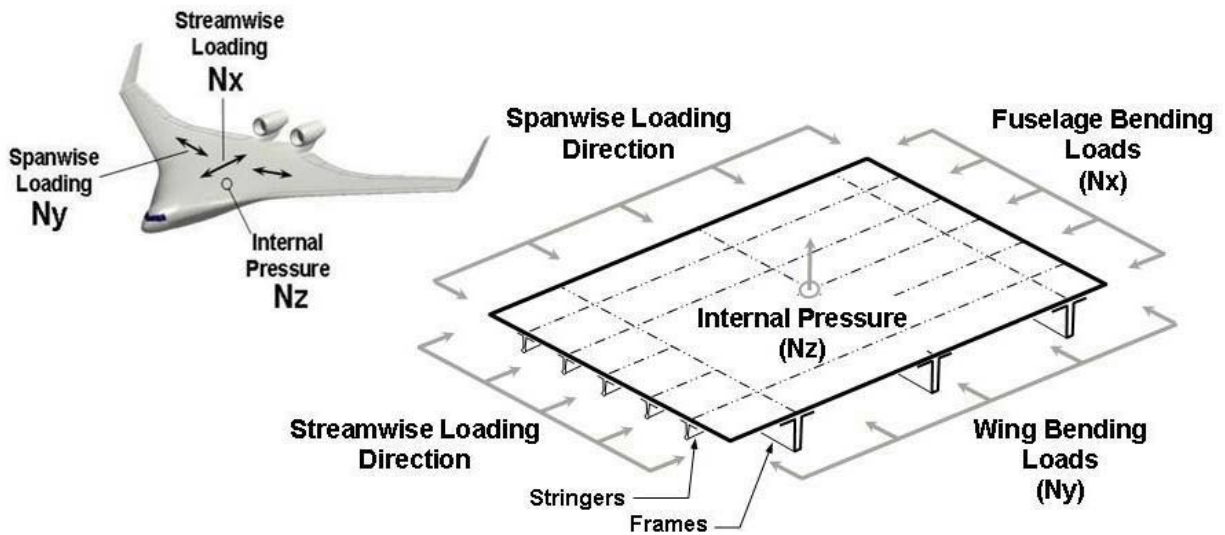


Figure 2. HWB conceptual vehicle and loading patterns.

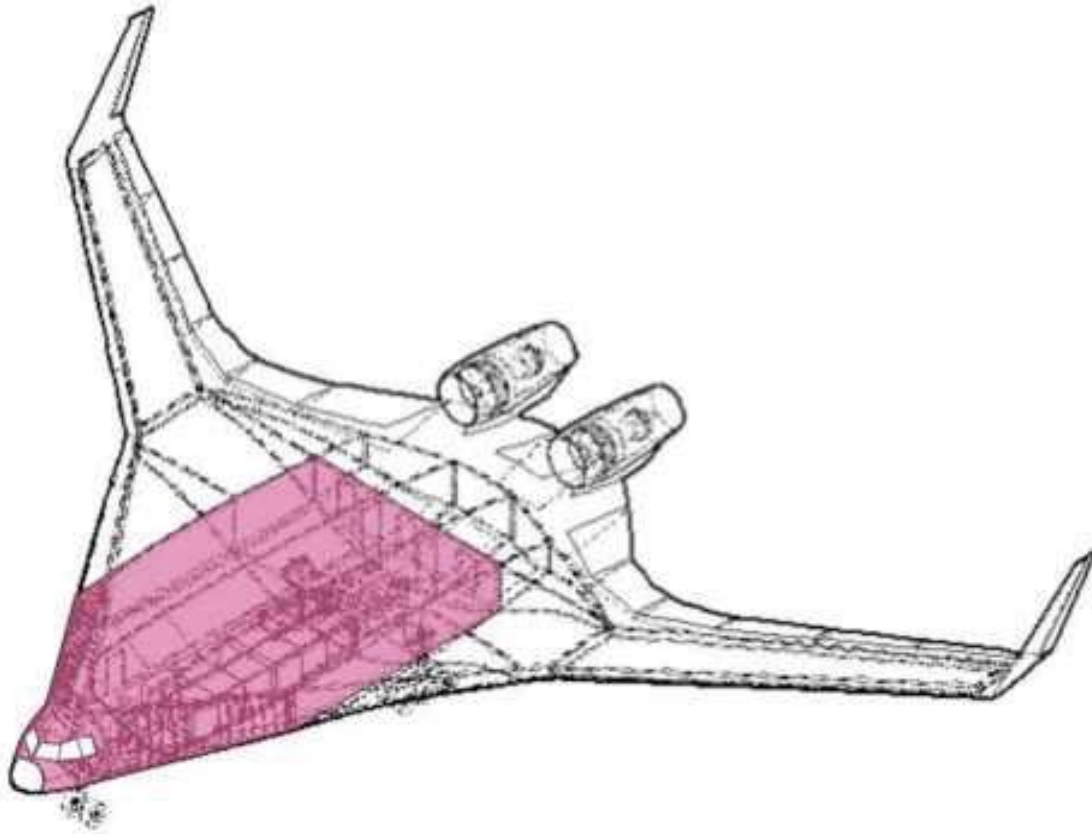


Figure 3. Typical pressurized portion of a HWB aircraft concept.

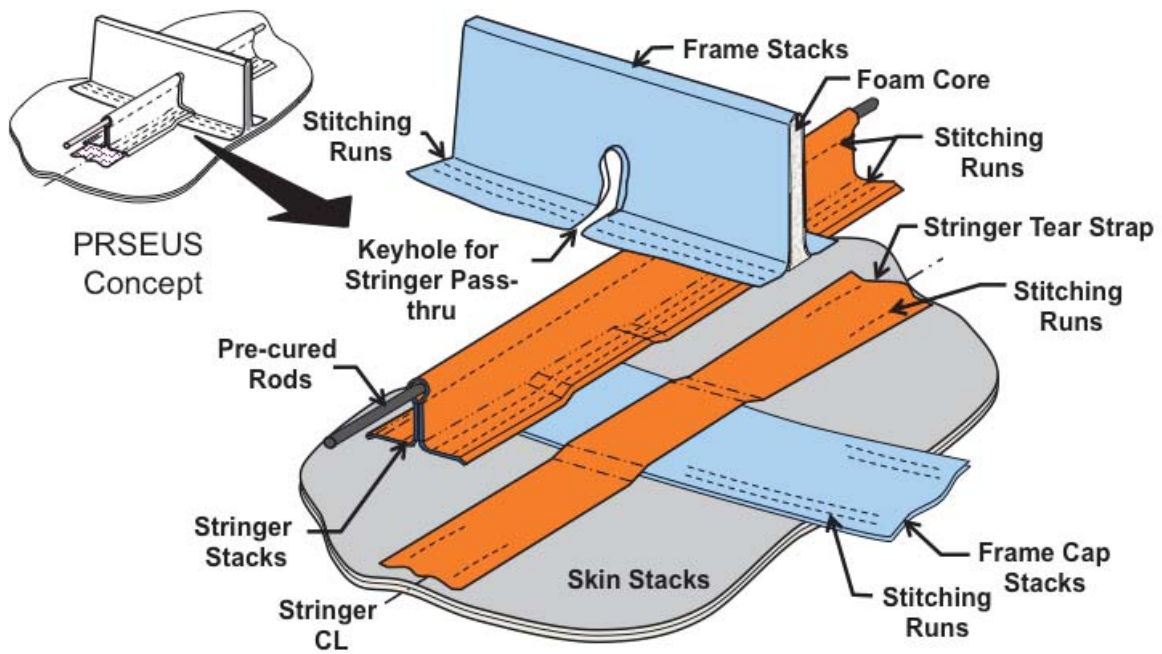


Figure 4. PRSEUS stiffener intersection expanded view.

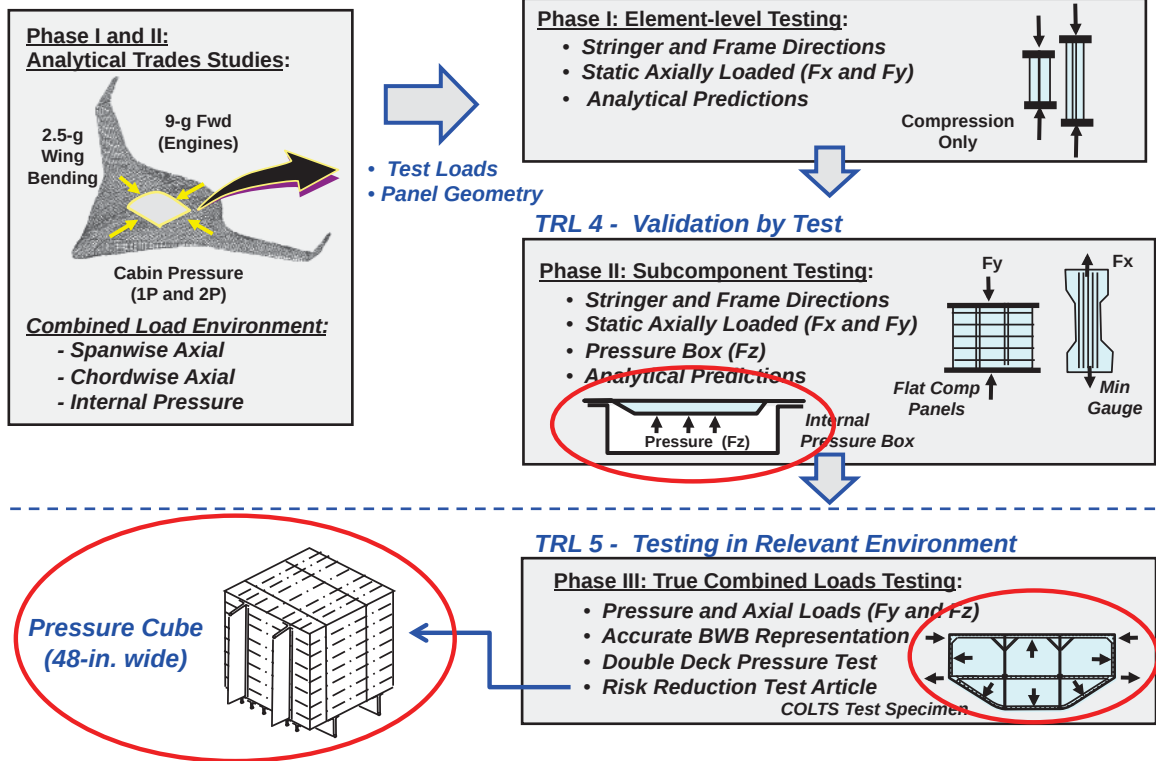


Figure 5. HWB structural development building block approach.

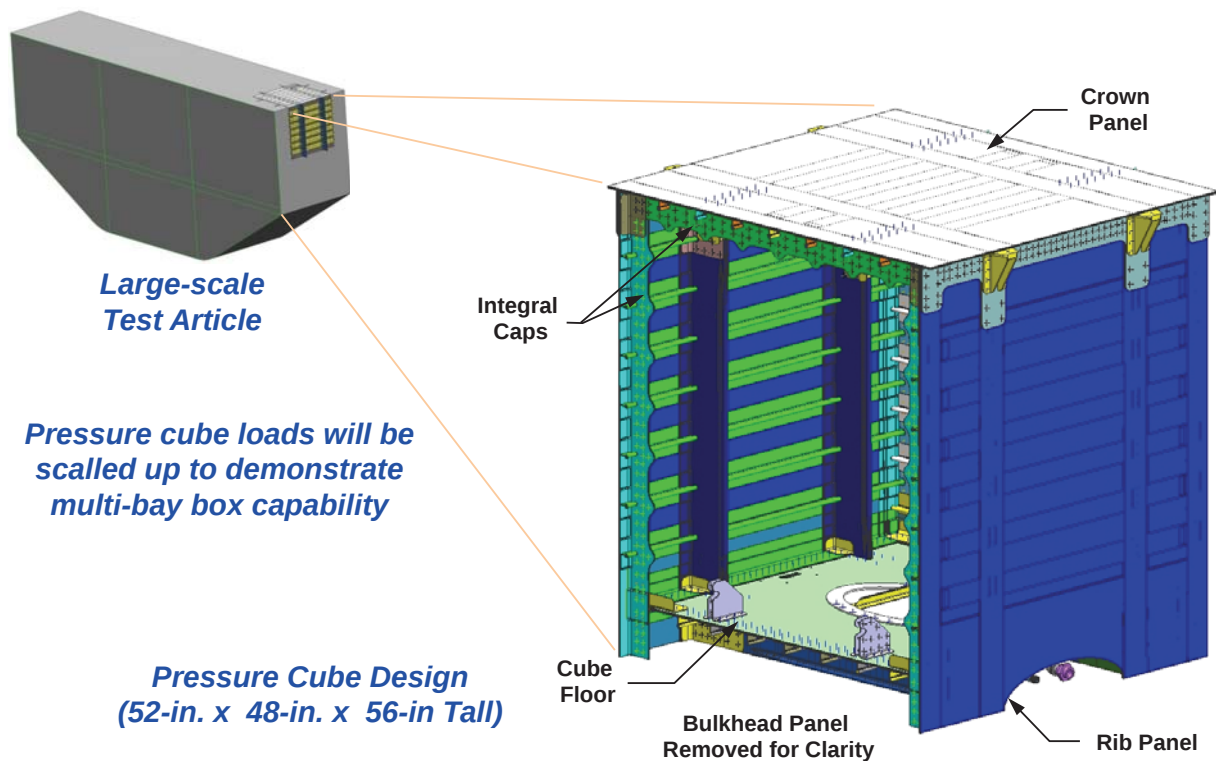


Figure 6. PRSEUS pressure cube is a representative section of the HWB large-scale test article.

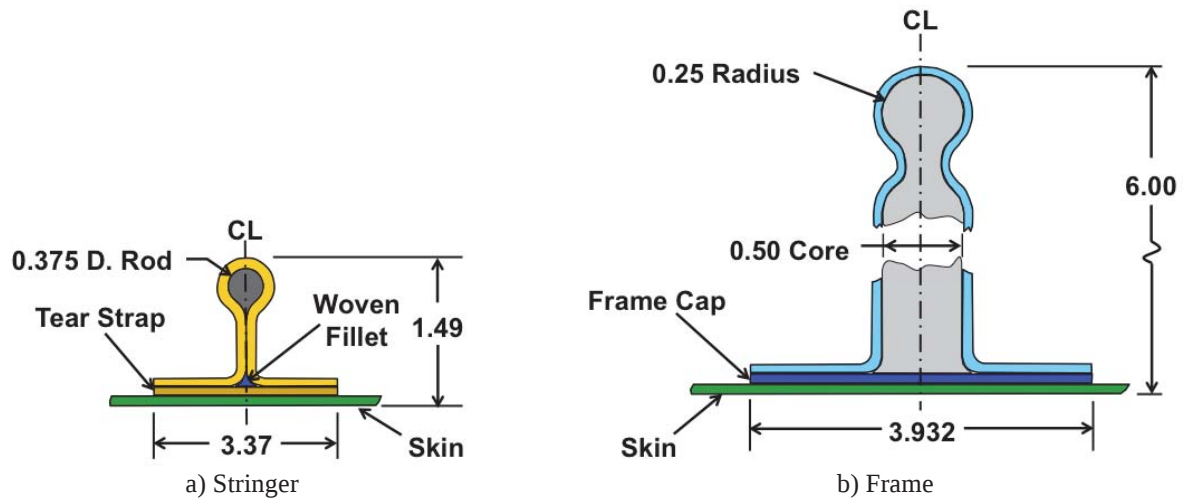


Figure 7. PRSEUS panel stringer and frame cross-sections. Dimensions are in inches.



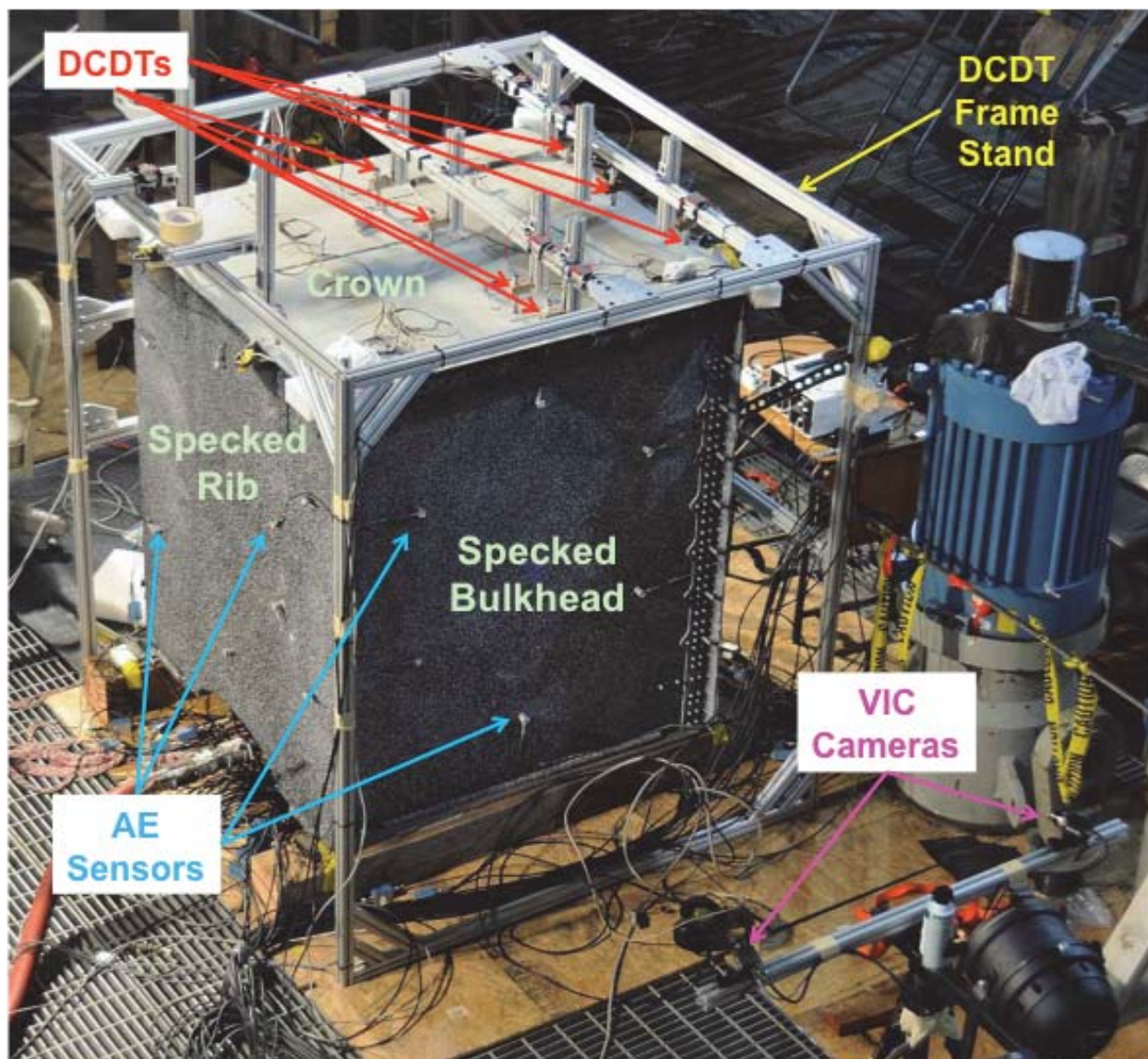


Figure 8. Pressure cube test set-up in the COLTS facility at NASA LaRC.



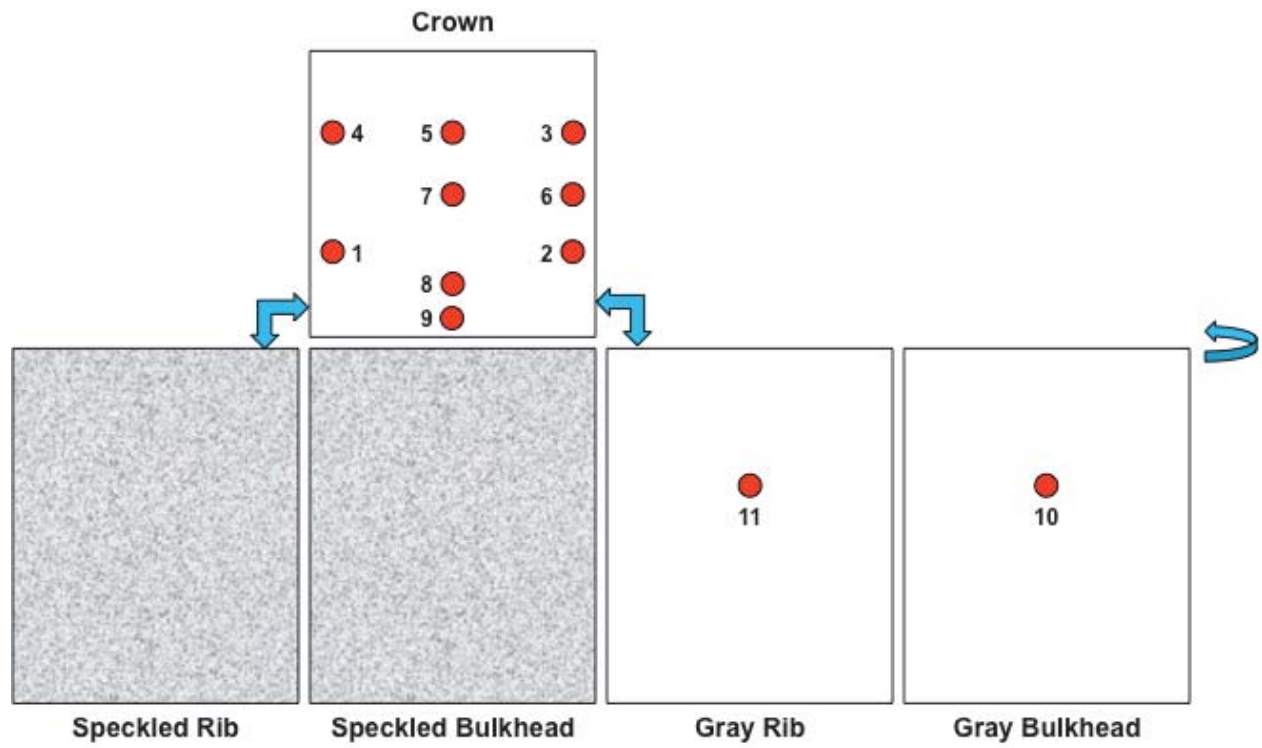


Figure 9. DCDT locations.

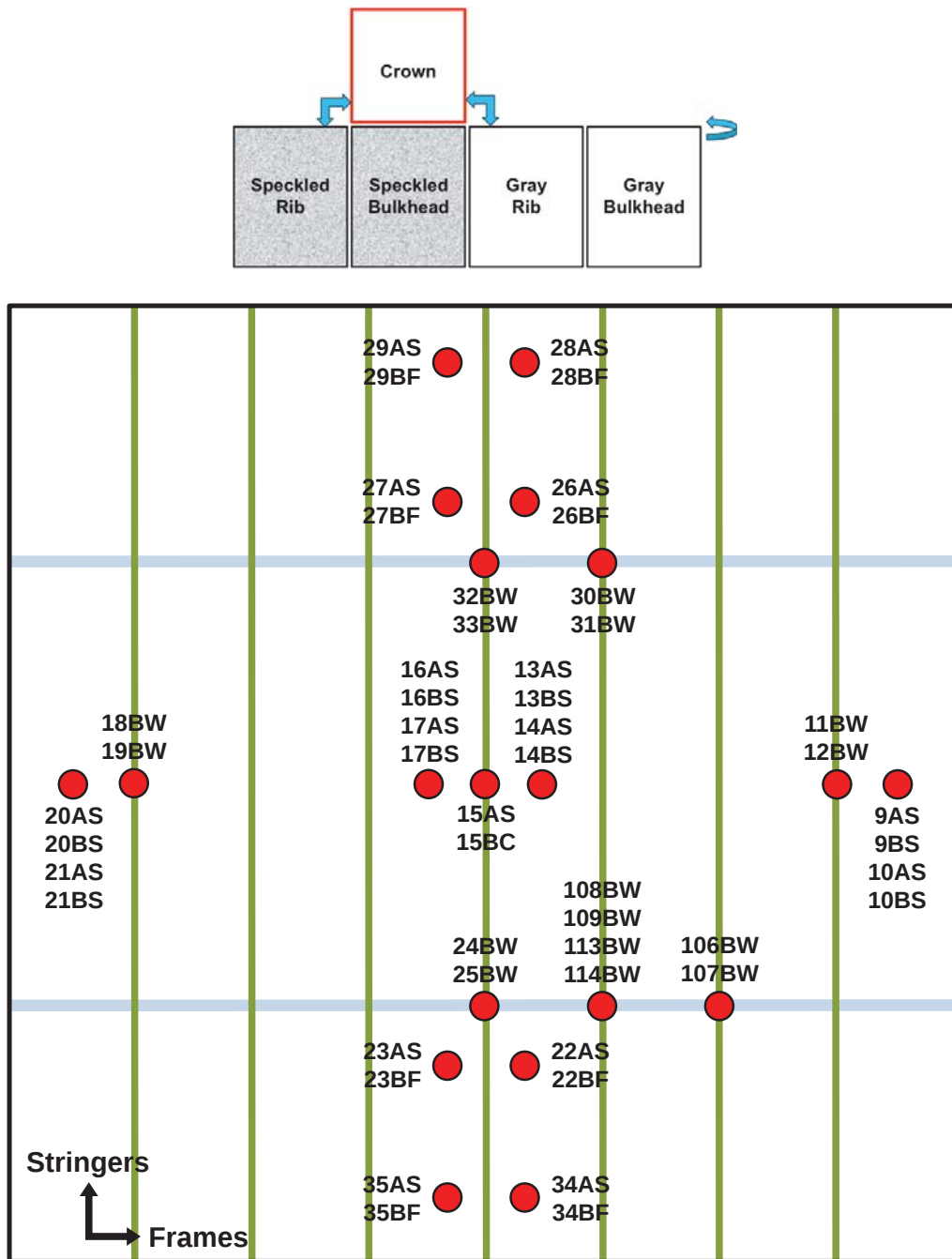
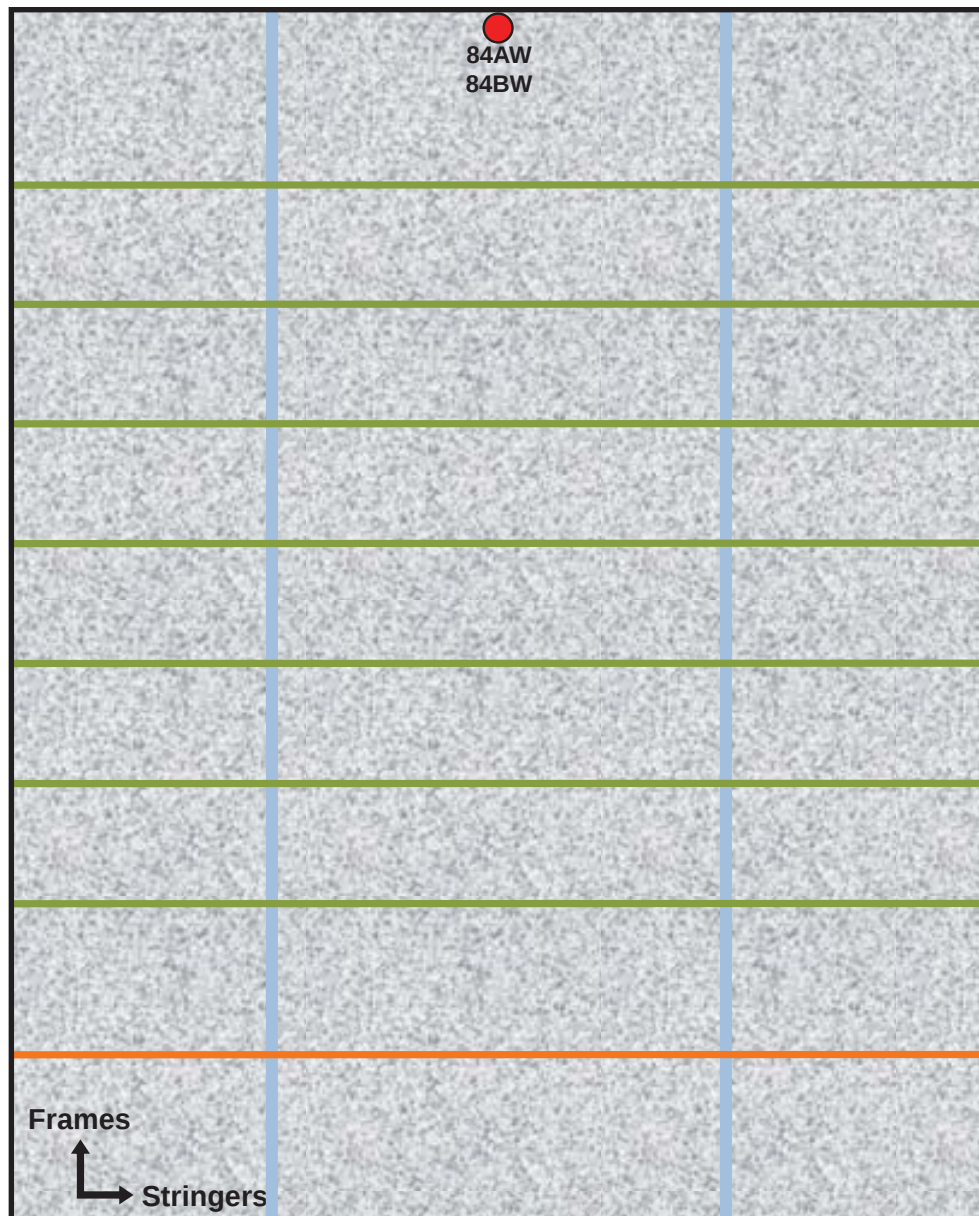
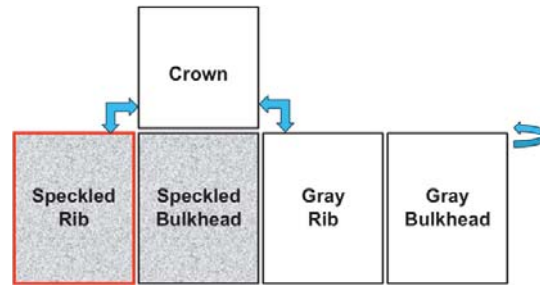


Figure 10. Crown strain gage locations.



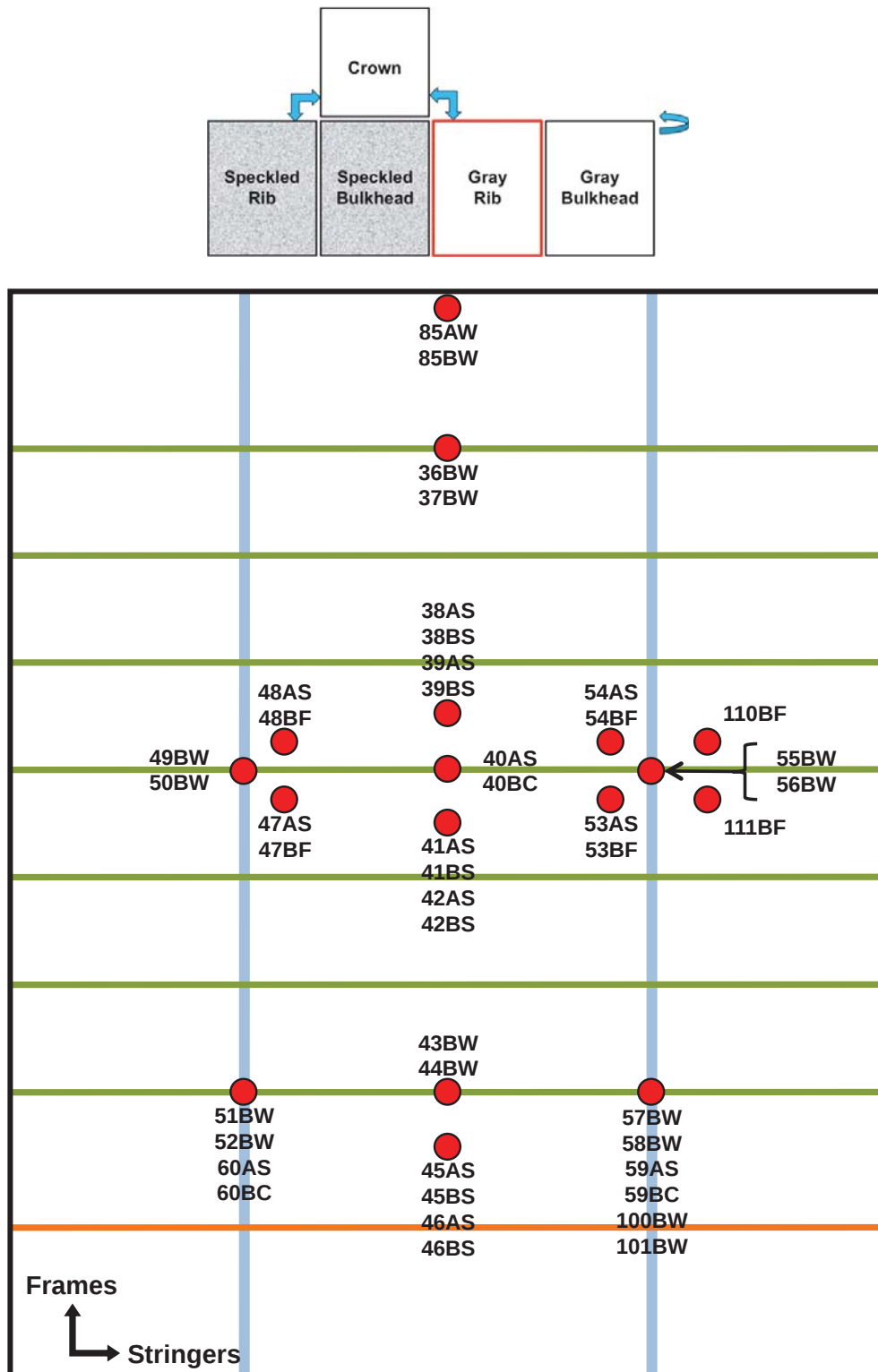
Terminology: A indicates OML, B indicates IML, S indicates skin, W indicates web, F indicates flange and C indicates cap.

Figure 11. Speckled rib strain gage locations.



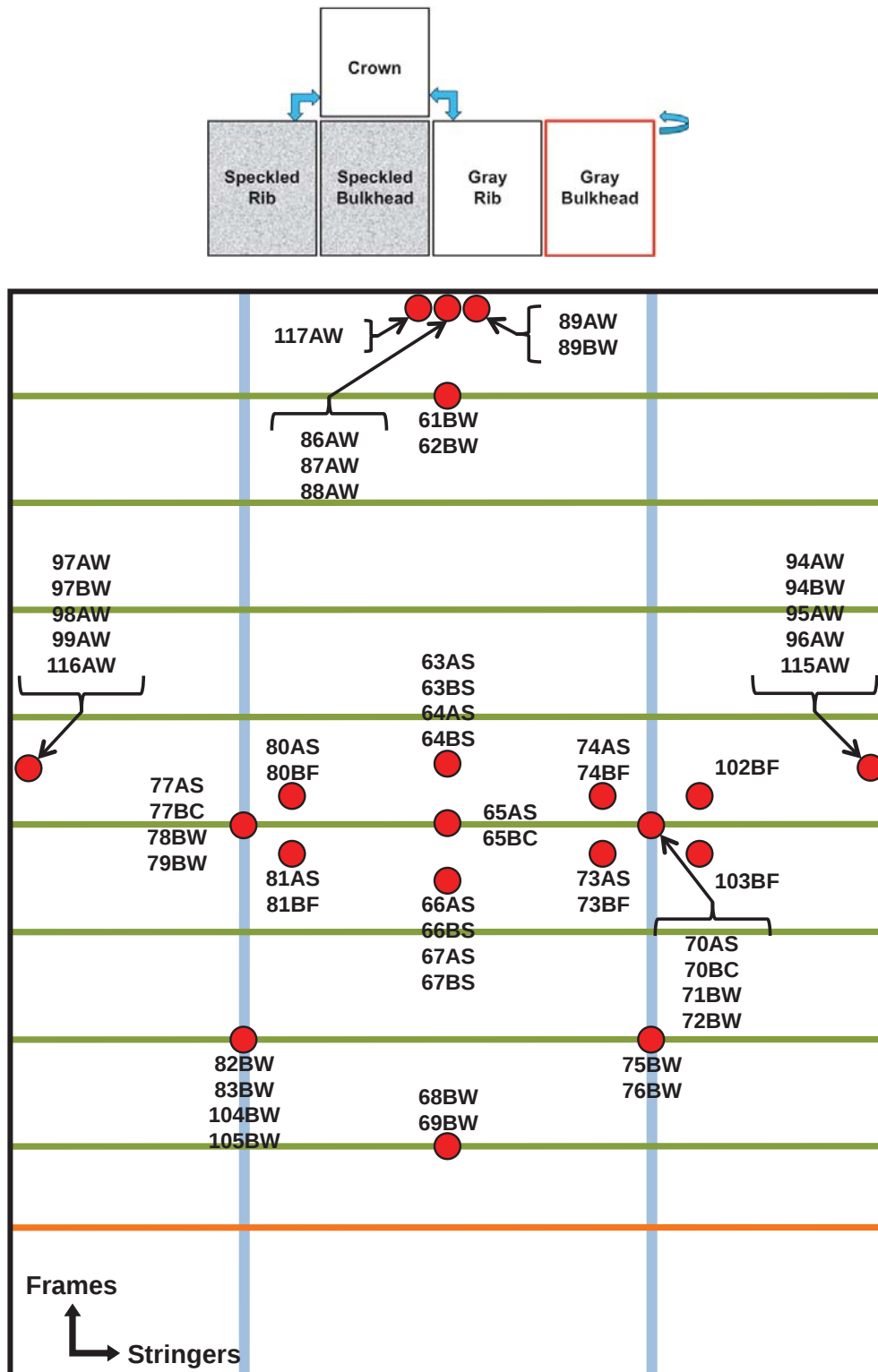
Terminology: A indicates OML, B indicates IML, S indicates skin, W indicates web, F indicates flange and C indicates cap.

Figure 12. Speckled bulkhead strain gage locations.



Terminology: A indicates OML, B indicates IML, S indicates skin, W indicates web, F indicates flange and C indicates cap.

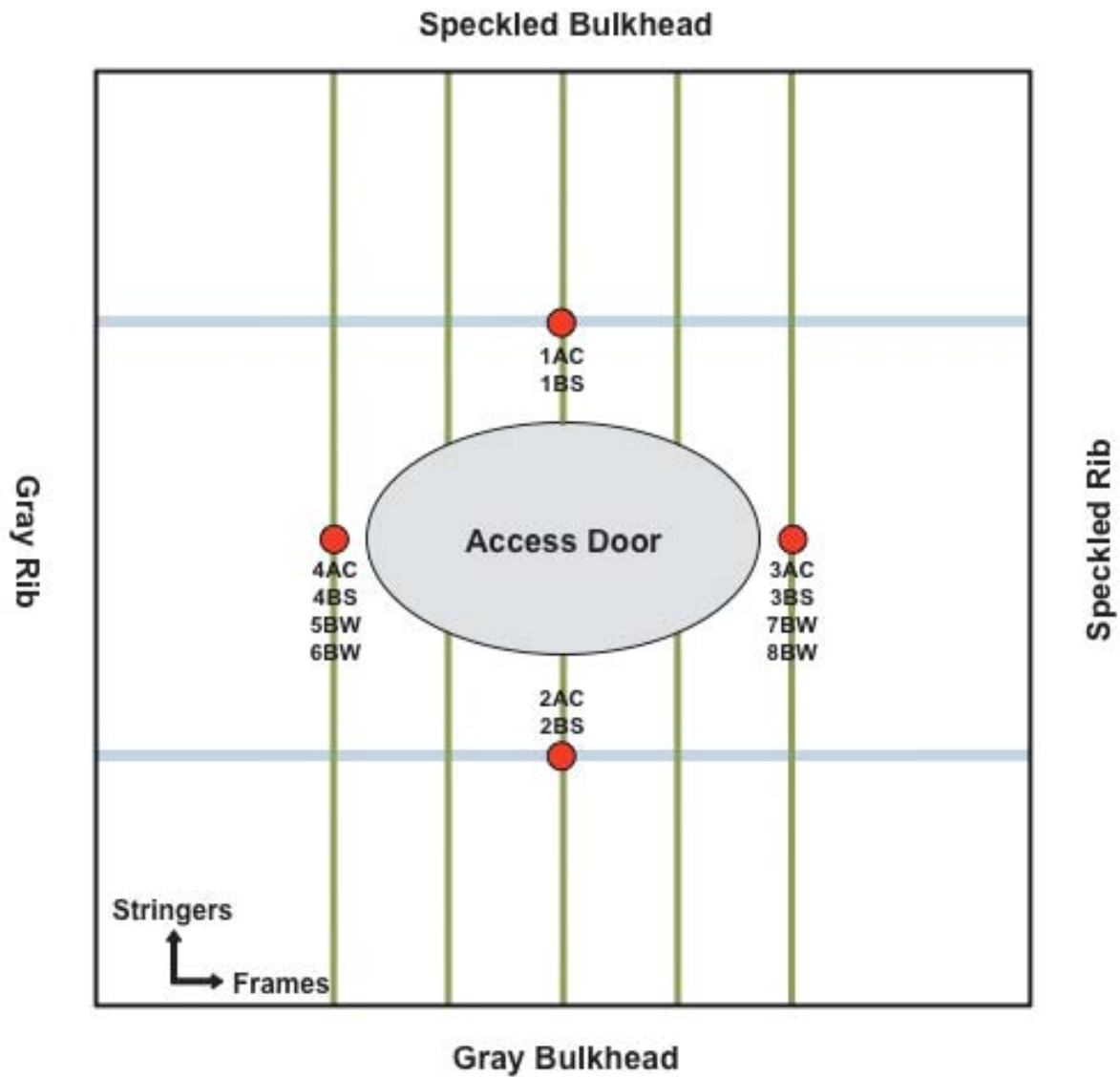
Figure 13. Gray rib strain gage locations.



Terminology: A indicates OML, B indicates IML, S indicates skin, W indicates web, F indicates flange and C indicates cap.

Figure 14. Gray bulkhesd strain gage locations.





Terminology: A indicates OML, B indicates IML, S indicates skin, W indicates web, F indicates flange and C indicates cap.

Figure 15. Floor strain gage locations.

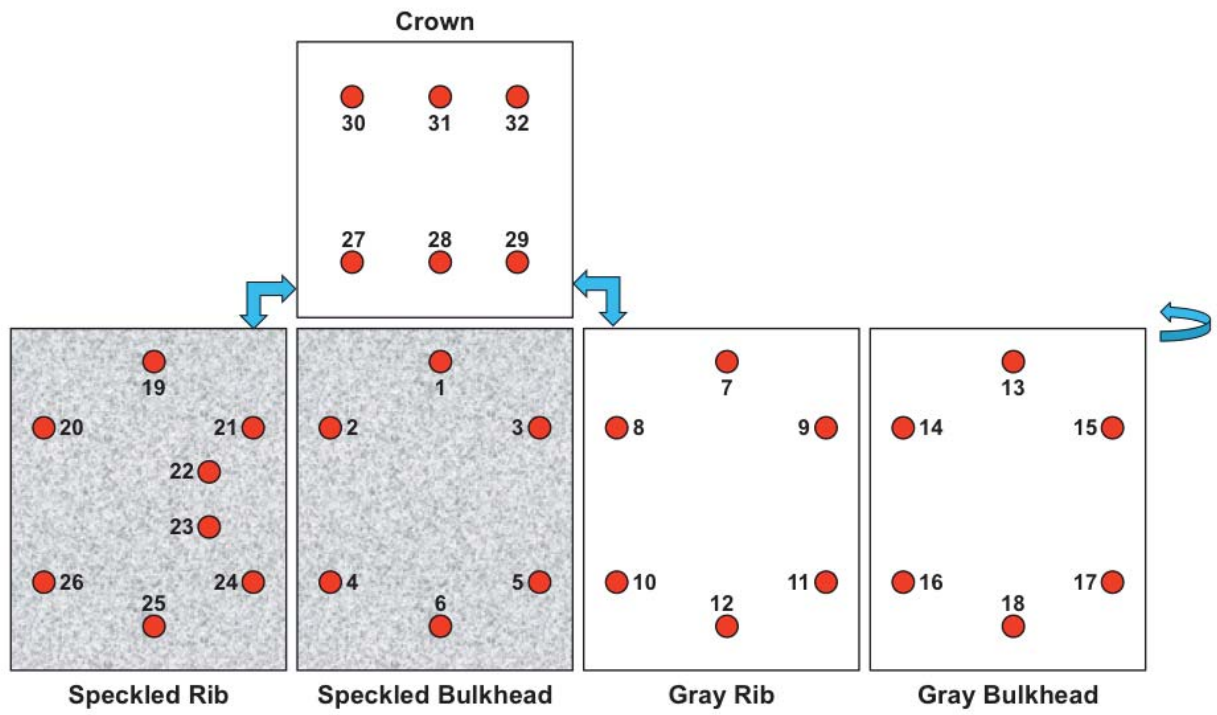


Figure 16. AE sensor placement and numbering.<sup>19</sup>

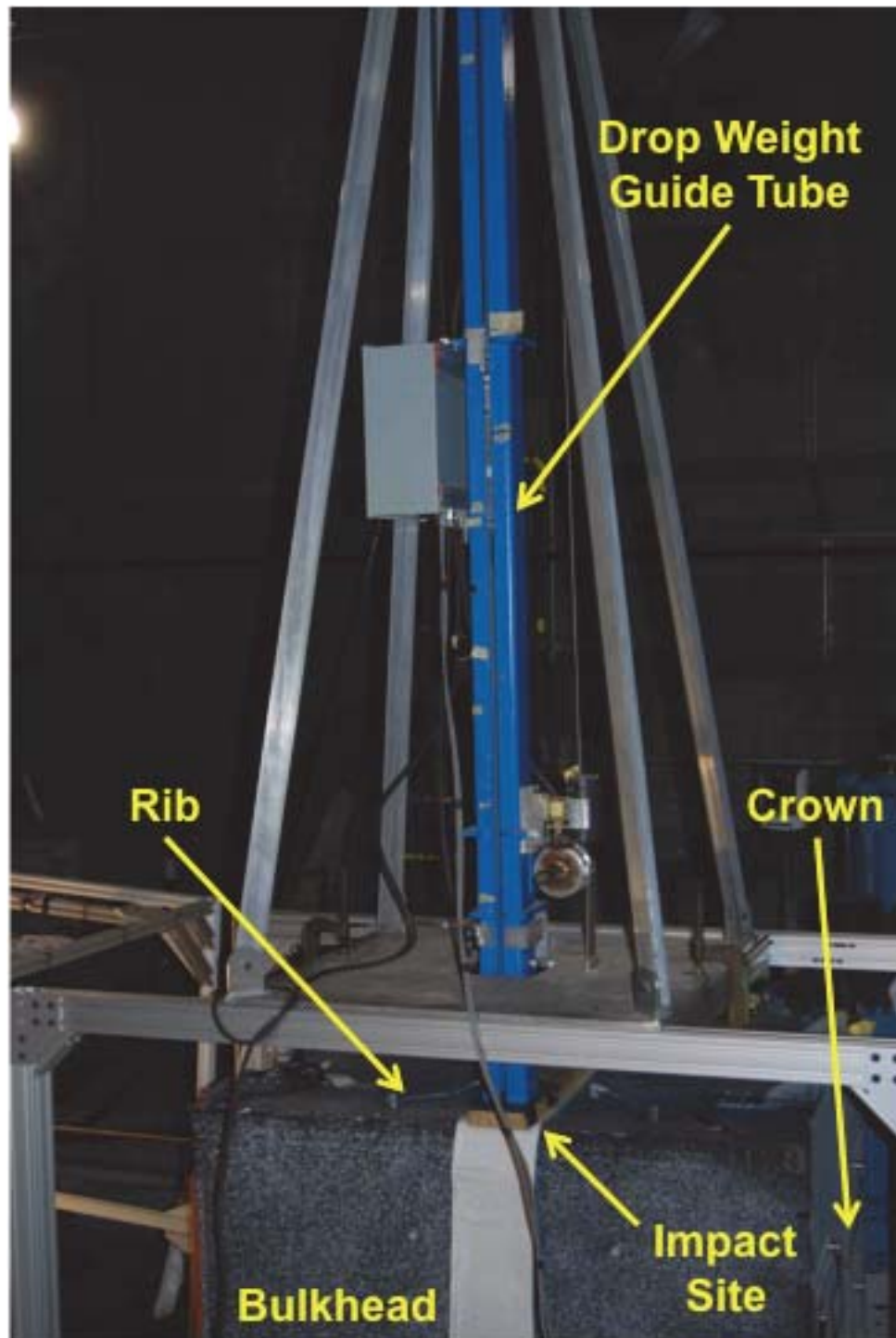


Figure 17. Set-up to impart BVID impact.

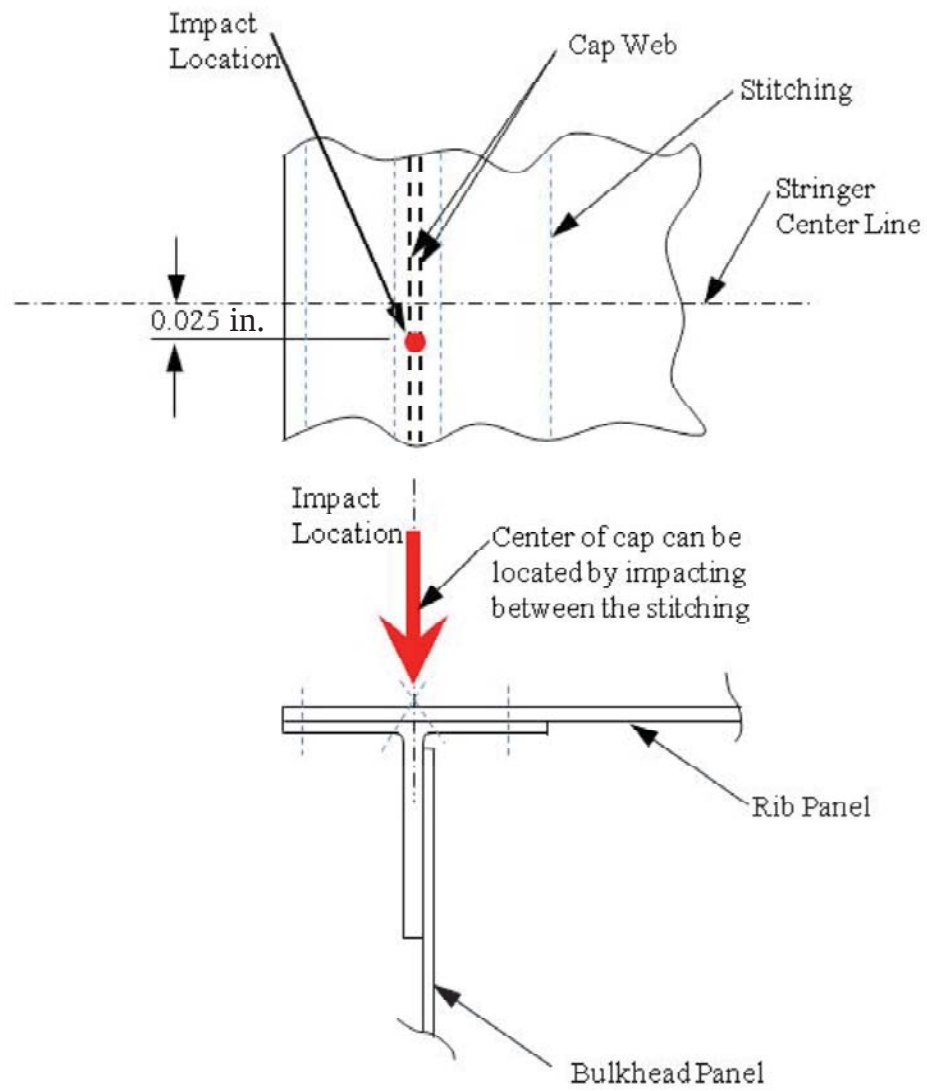


Figure 18. Relative location of the BVID with respect to the integral cap.

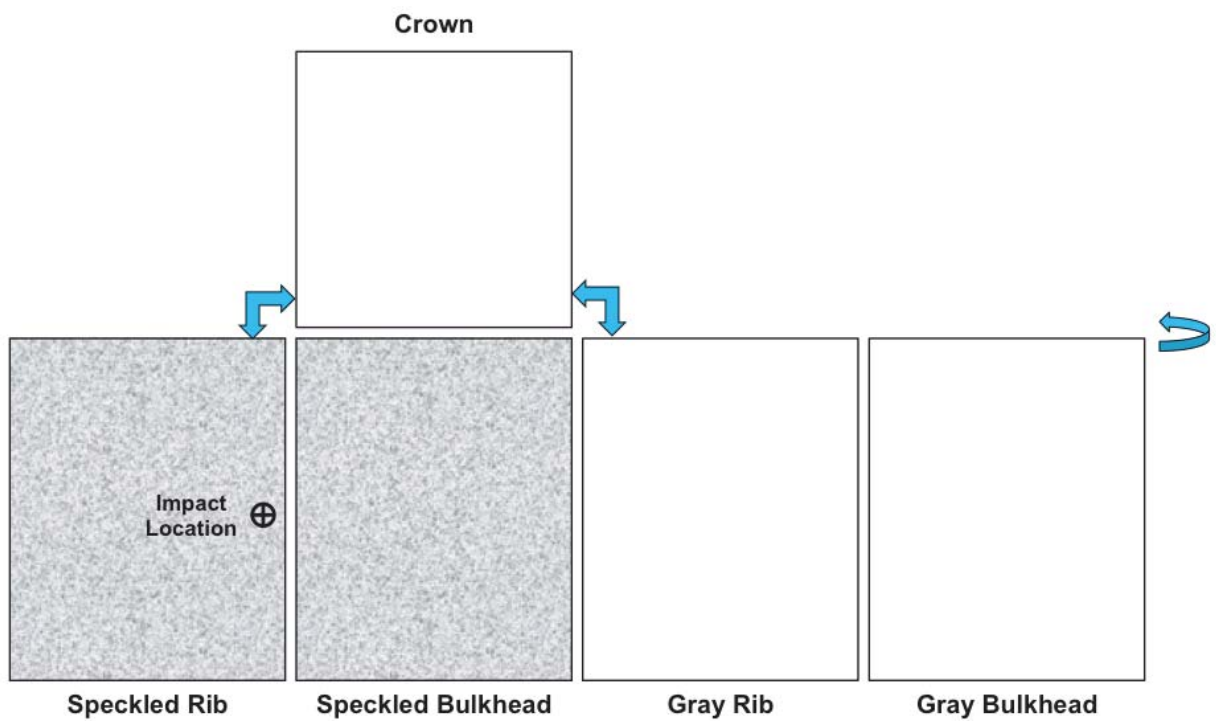
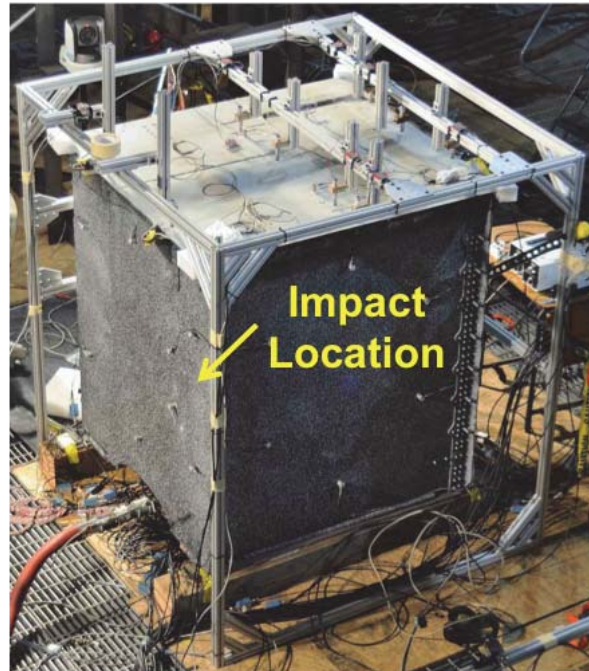


Figure 19. Location of the BVID with respect to the cube.



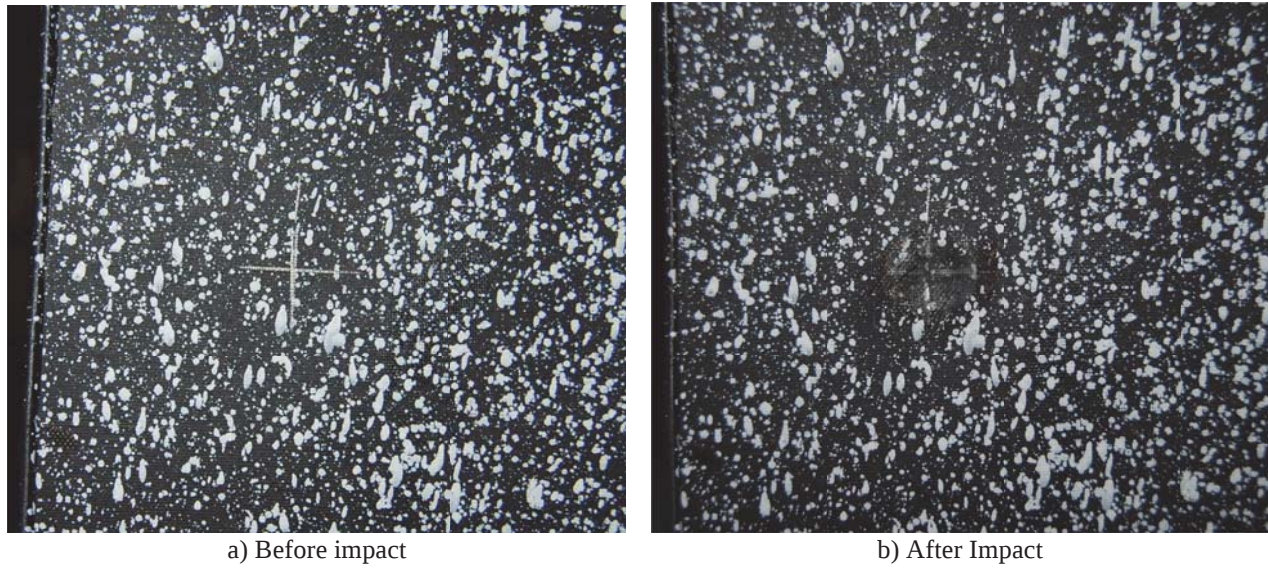


Figure 20. BVID location.

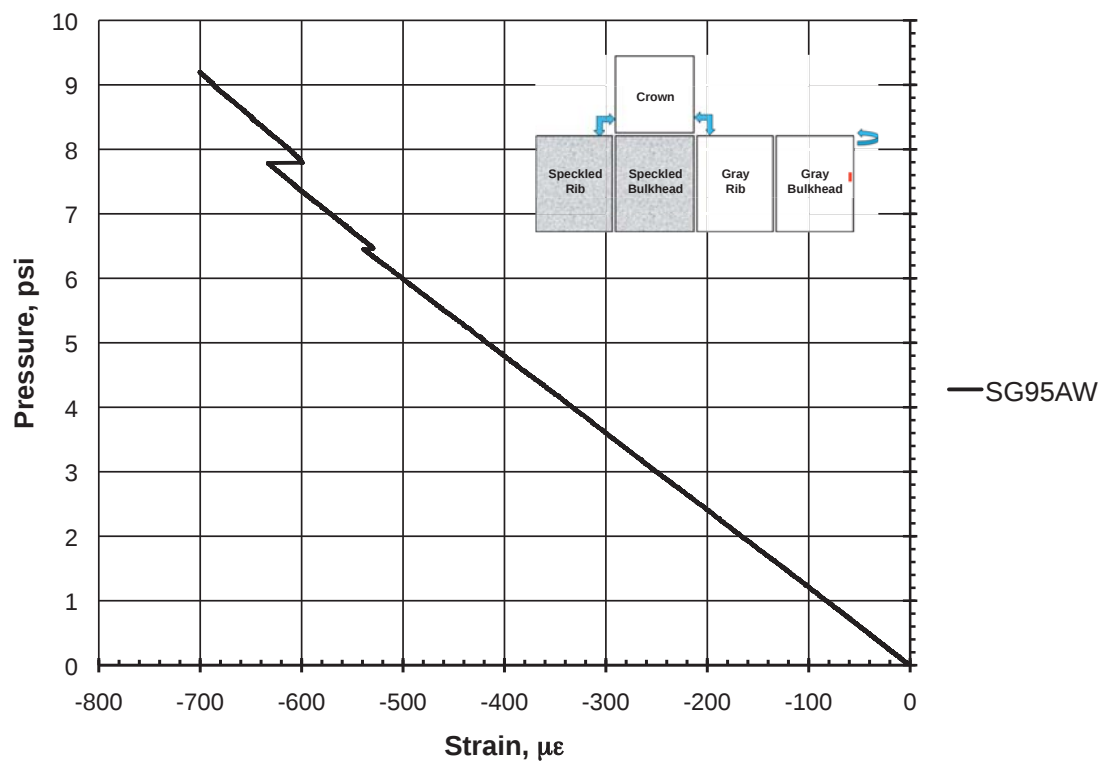


Figure 21. Response of strain gage SG95AW (OML, adjacent to stringer rod, parallel to frame) for loading up to 1P.



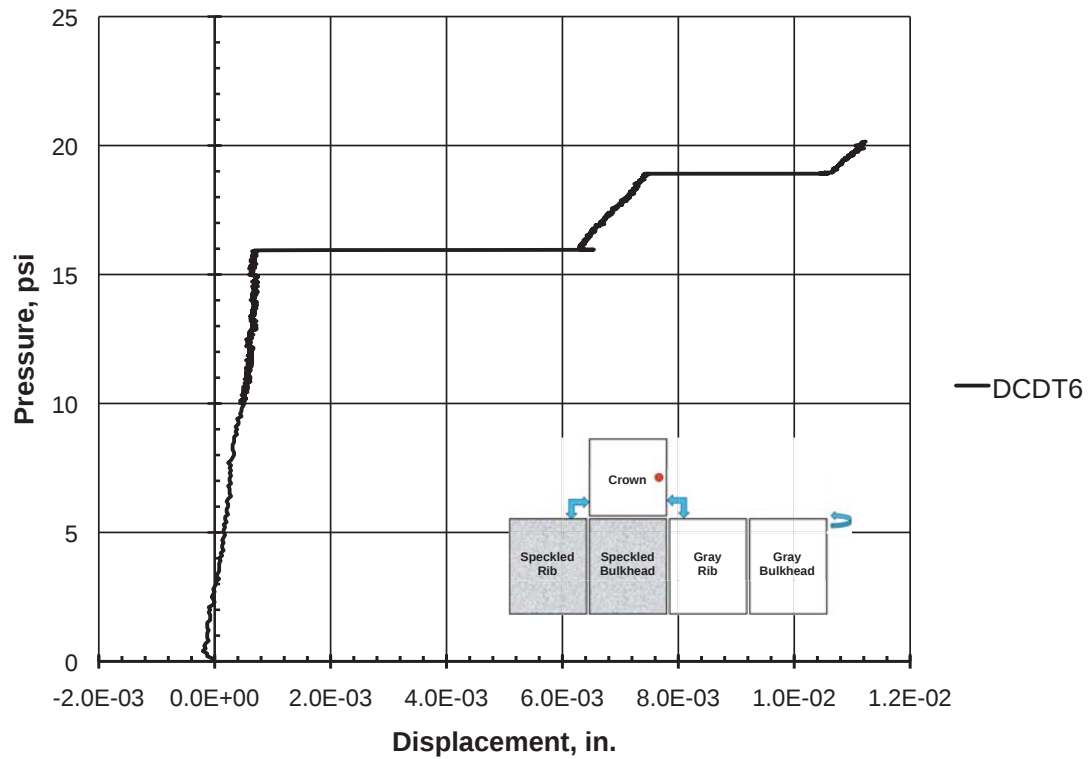


Figure 22. Normal displacement response of DCDT6 for loading up to 2.2P.

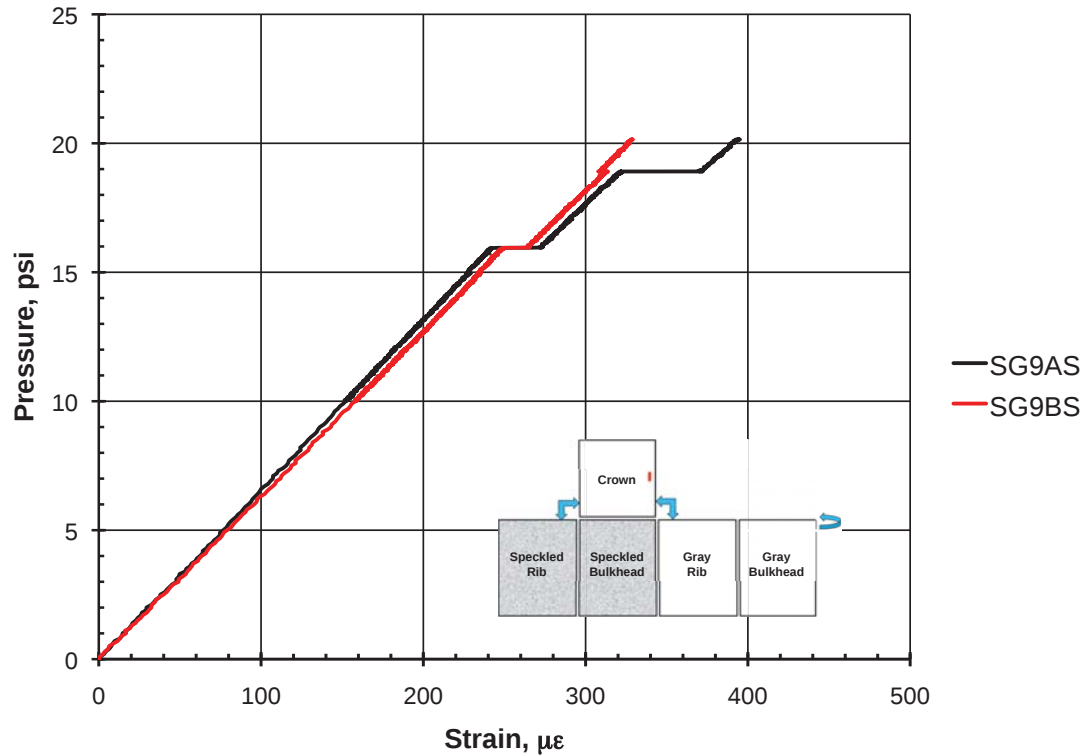


Figure 23. Response of strain gages SG9AS (OML) and SG9BS (IML) for loading up to 2.2P.

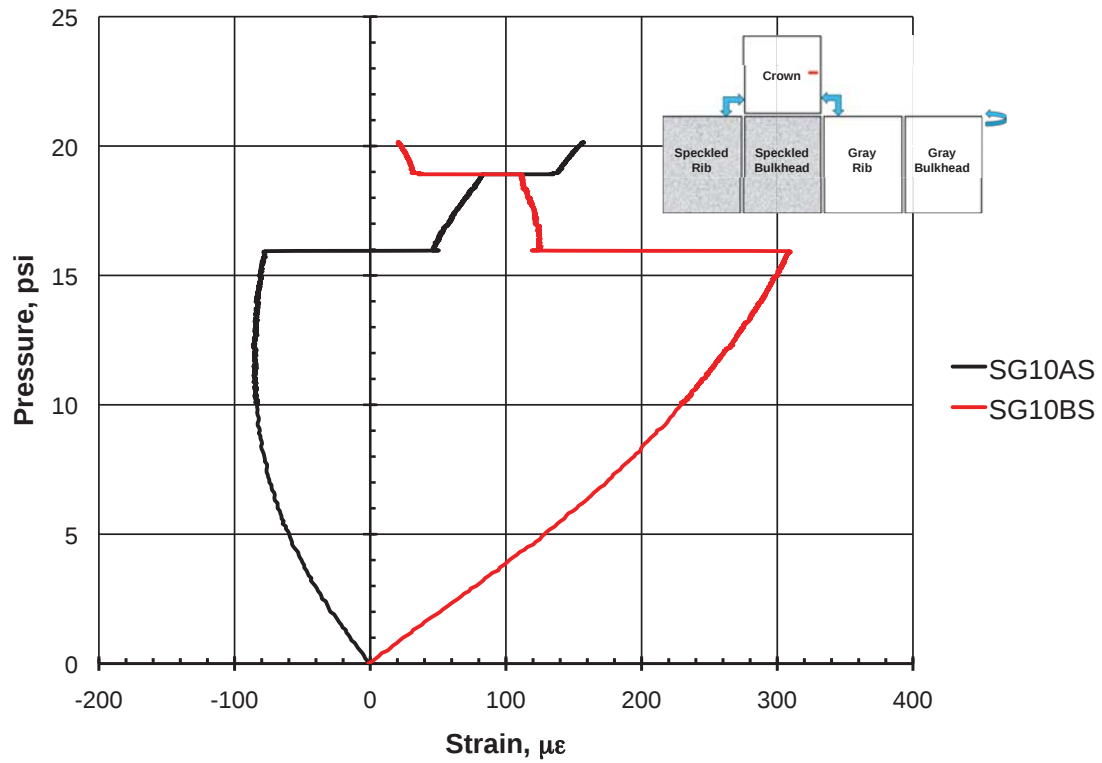


Figure 24. Response of strain gages SG10AS (OML) and SG10BS (IML) for loading up to 2.2P.

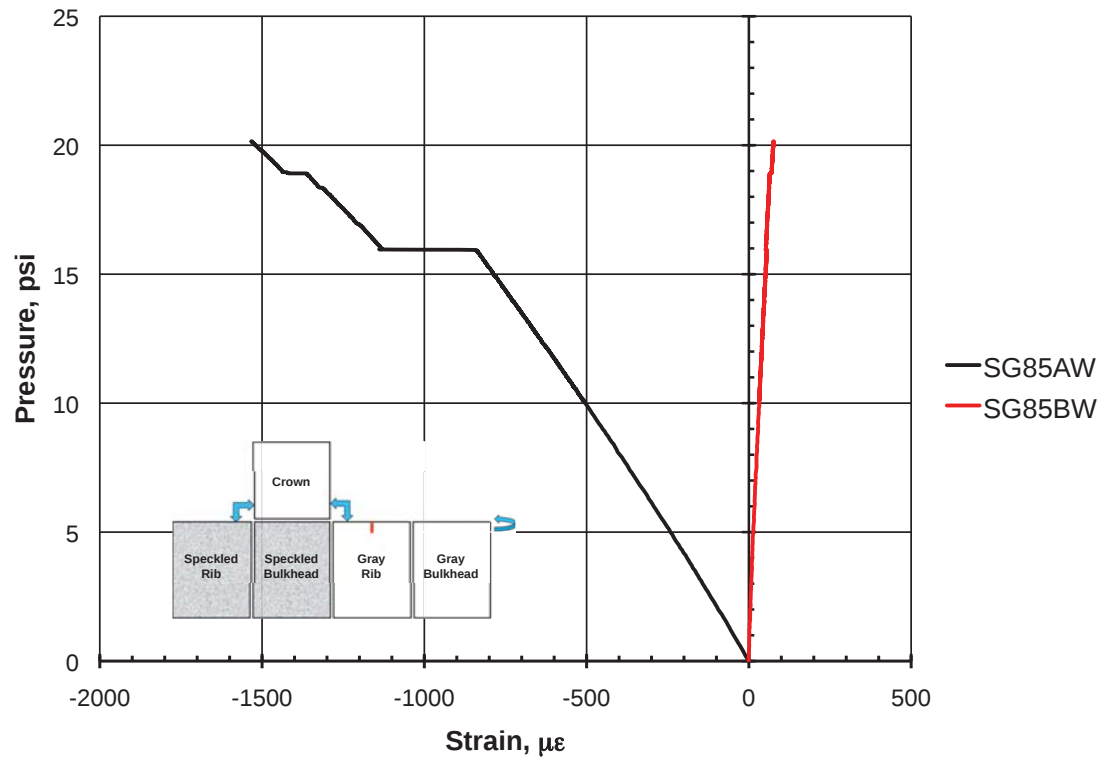


Figure 25. Response of strain gages SG85AW (OML) and SG85BW (IML) for loading up to 2.2P.

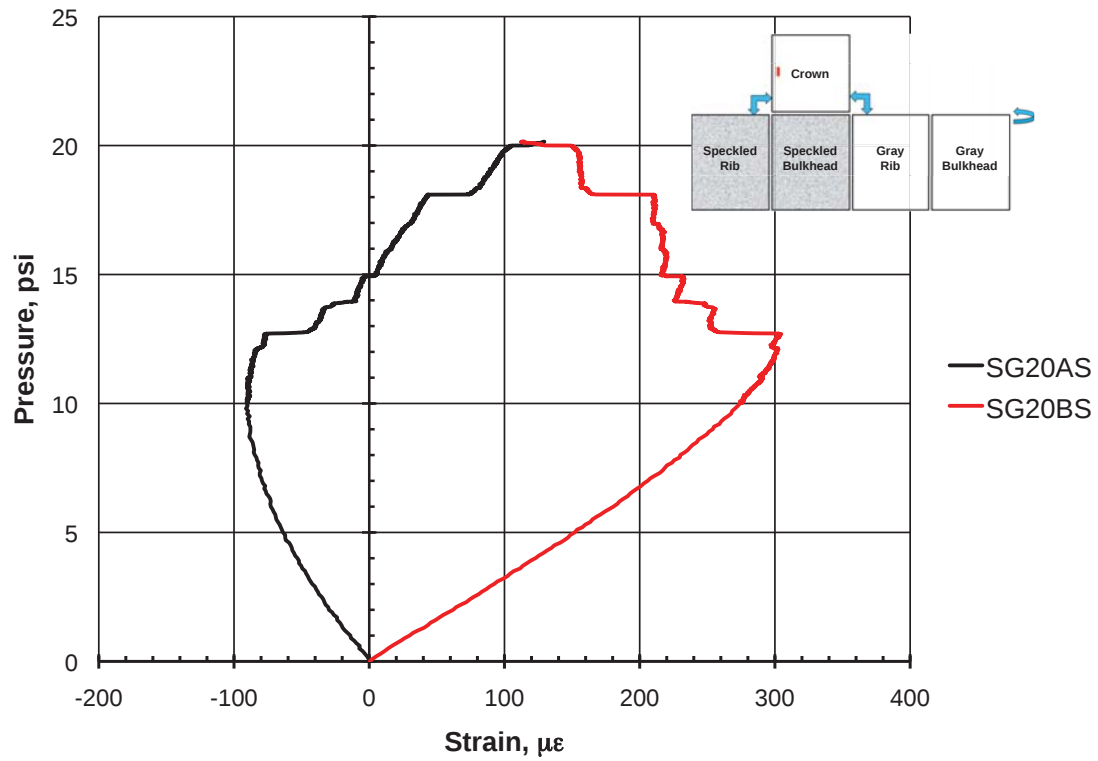


Figure 26. Response of strain gages SG20AS (OML) and SG20BS (IML) for loading up to 2.2P.

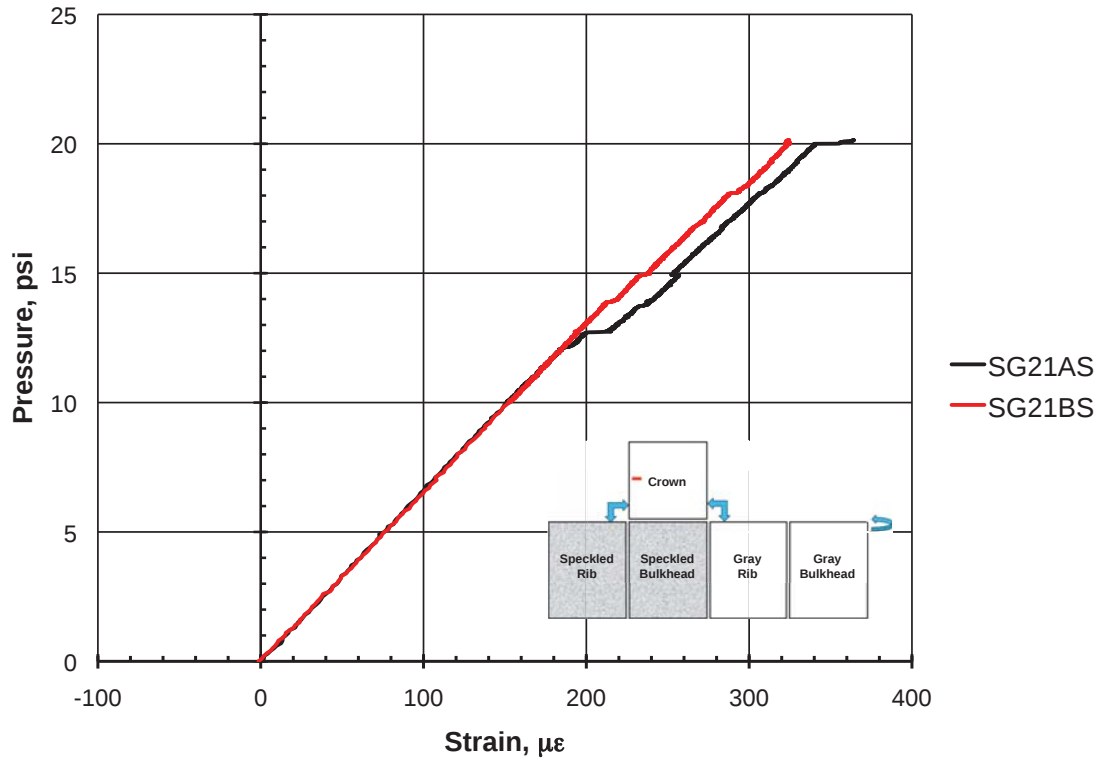


Figure 27. Response of strain gages SG21AS (OML) and SG21BS (IML) for loading up to 2.2P.

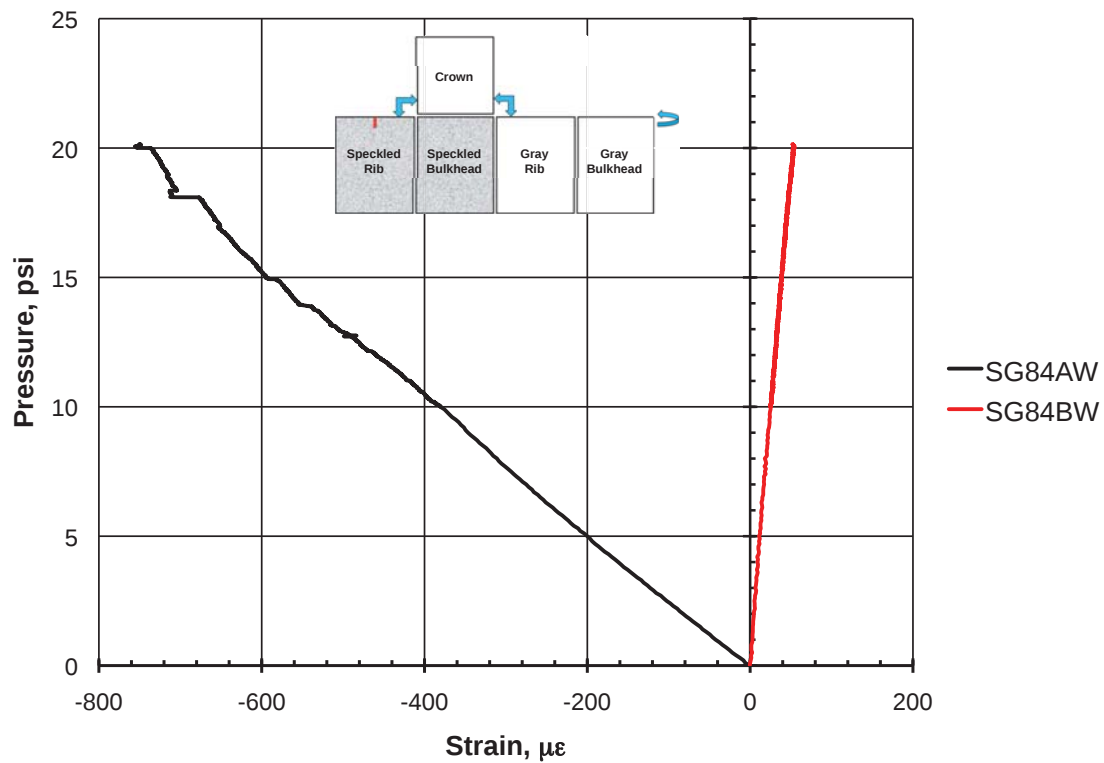


Figure 28. Response of strain gages SG84AW (OML) and SG84BW (IML) for loading up to 2.2P.

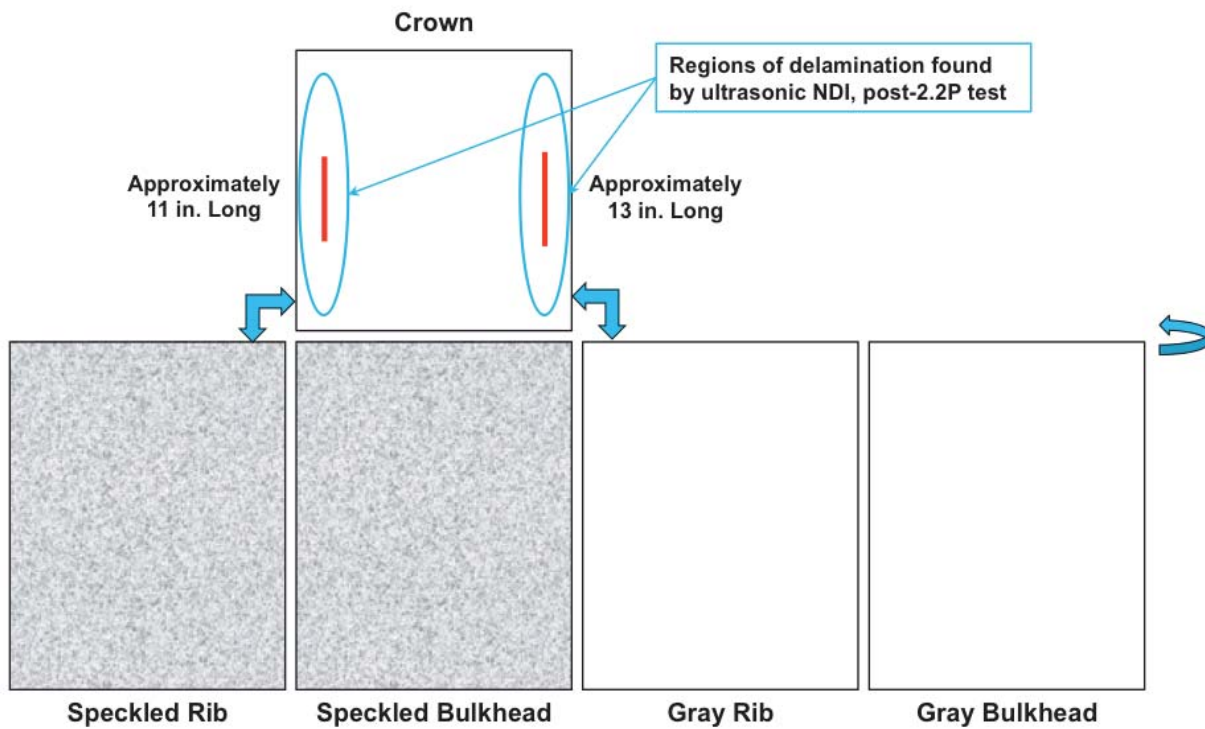


Figure 29. Locations of delamination as identified by NDI.<sup>21</sup>

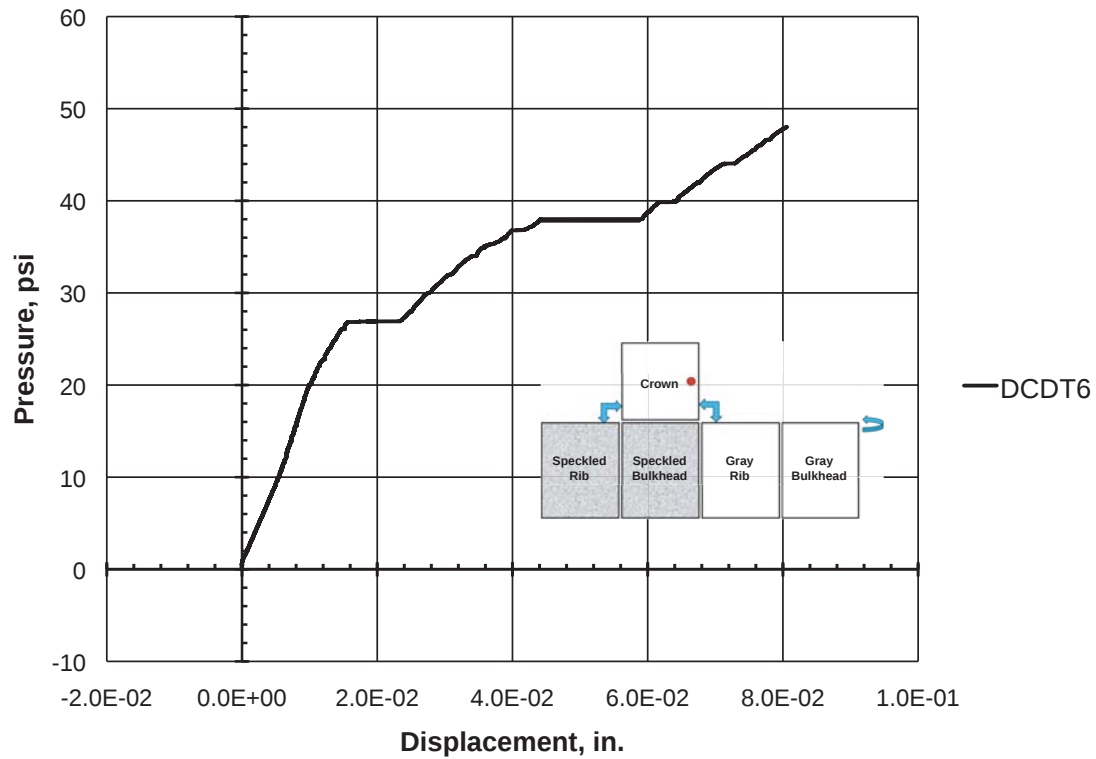


Figure 30. Response of DCDT6 for loading up to catastrophic failure (at crown delamination location).

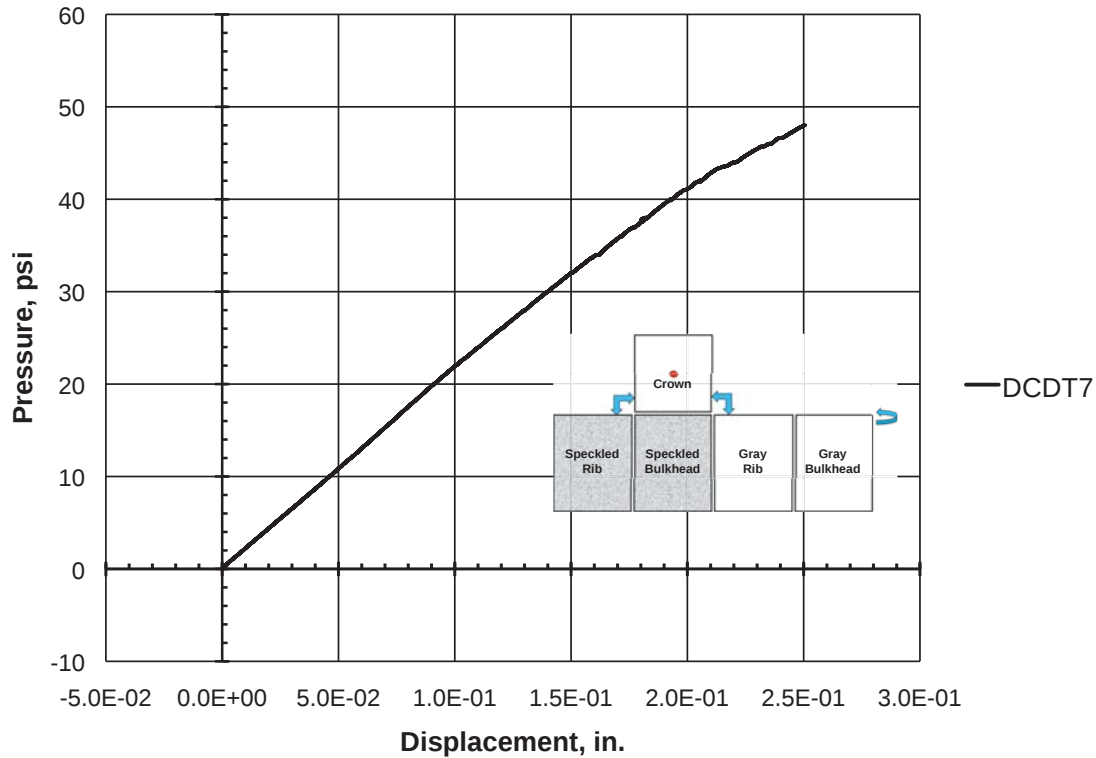


Figure 31. Response of DCDT7 for loading up to catastrophic failure (at center of crown panel).

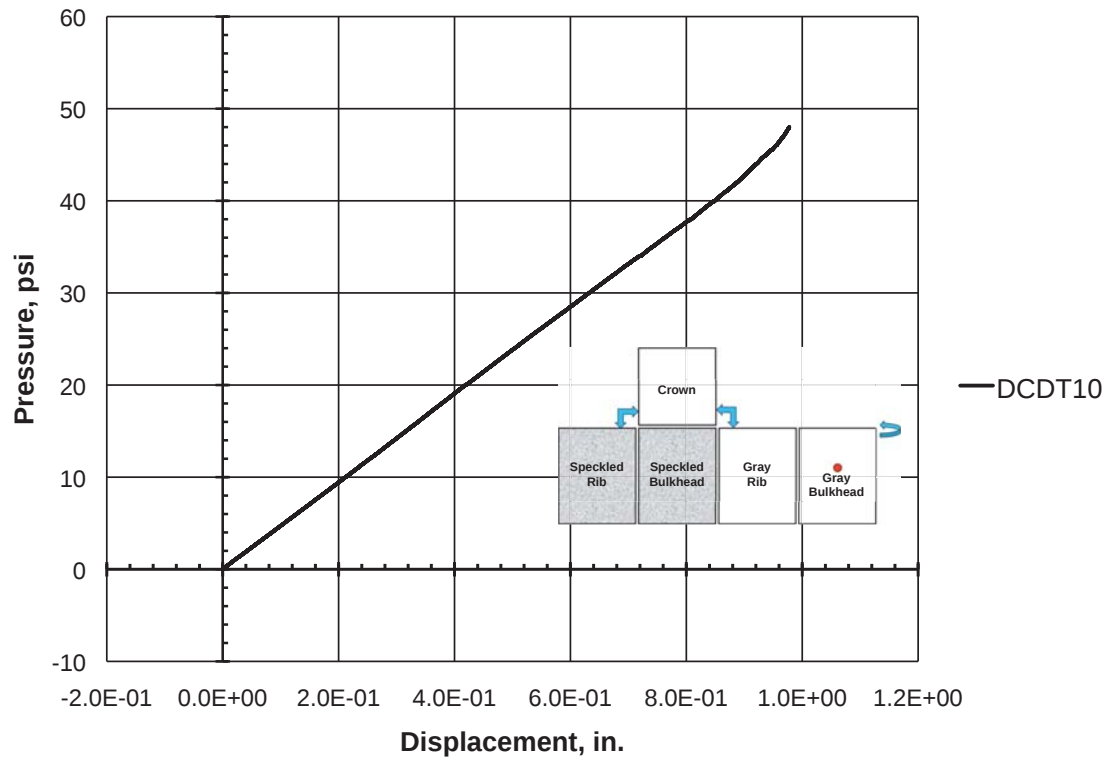


Figure 32. Response of DCDT10 for loading up to catastrophic failure (at center of gray bulkhead).

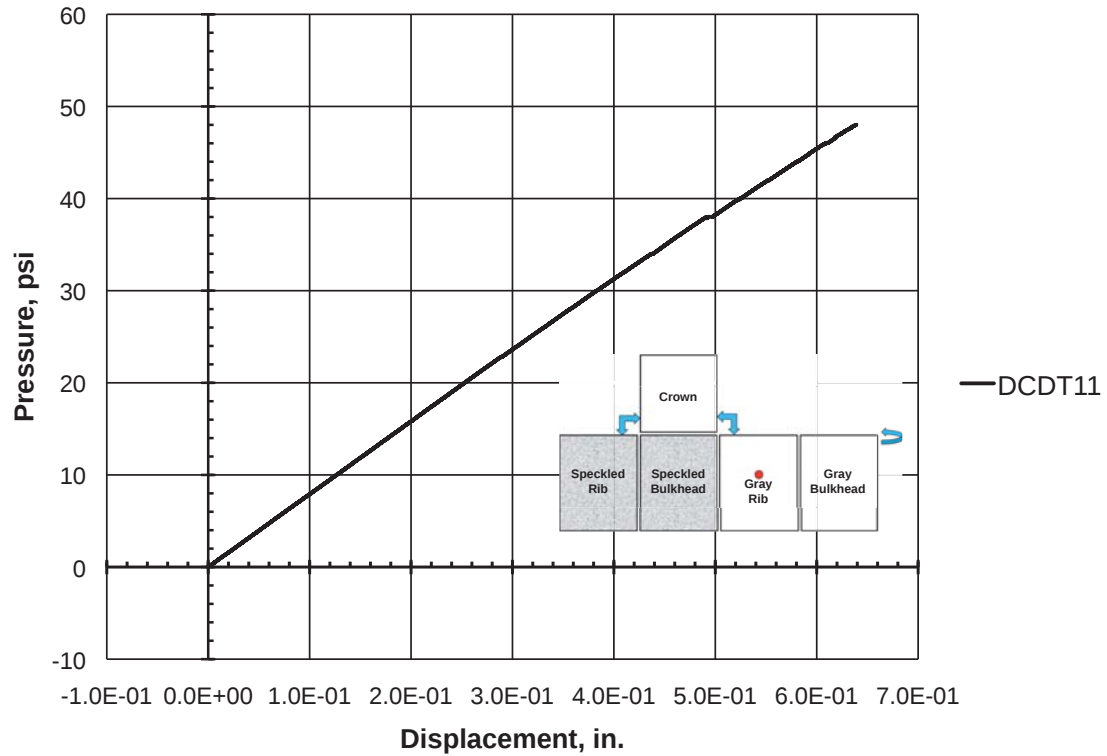


Figure 33. Response of DCDT11 for loading up to catastrophic failure (at center of gray rib).



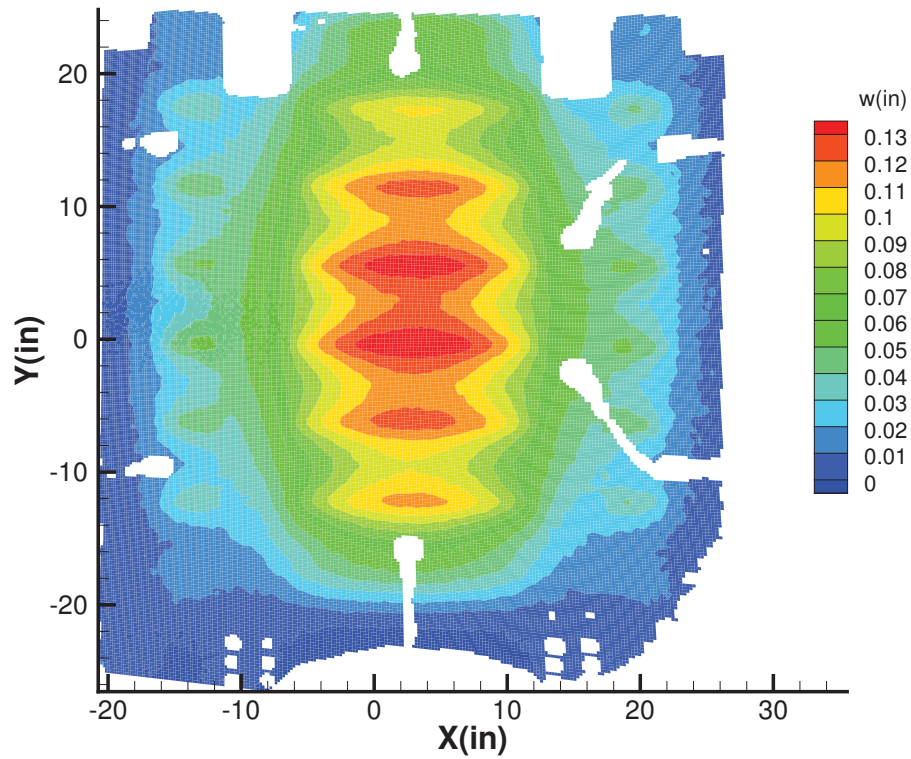


Figure 34. VIC normal displacement plot for speckled rib at 9.2 psi (1P). White spaces indicate areas where VIC data was not recorded.

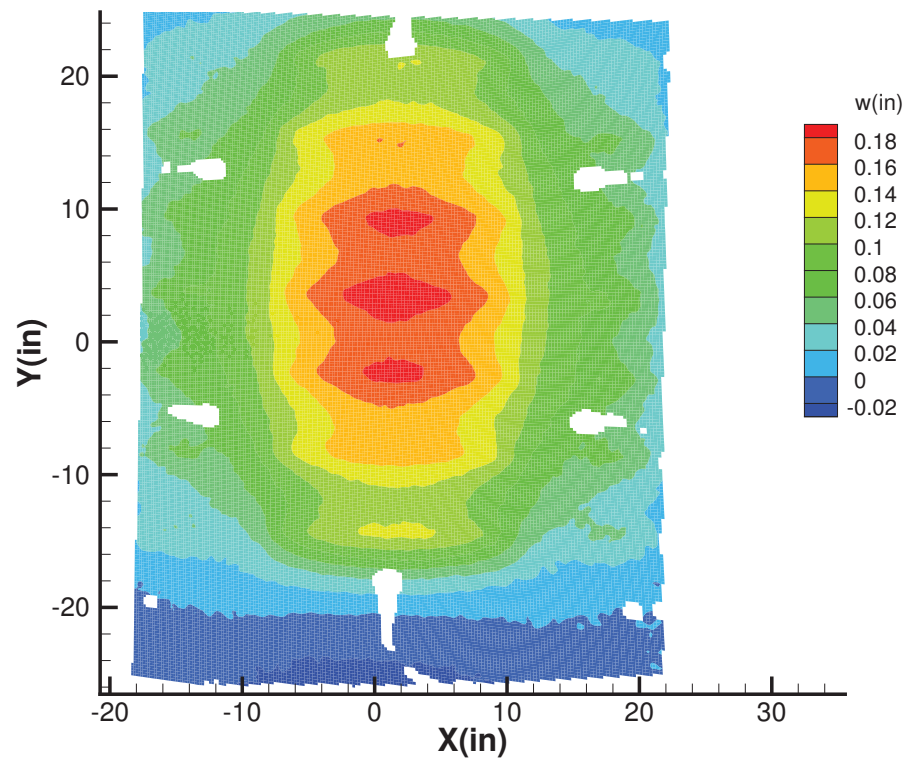


Figure 35. VIC normal displacement plot for speckled bulkhead at 9.2 psi (1P). White spaces indicate areas where VIC data was not recorded.

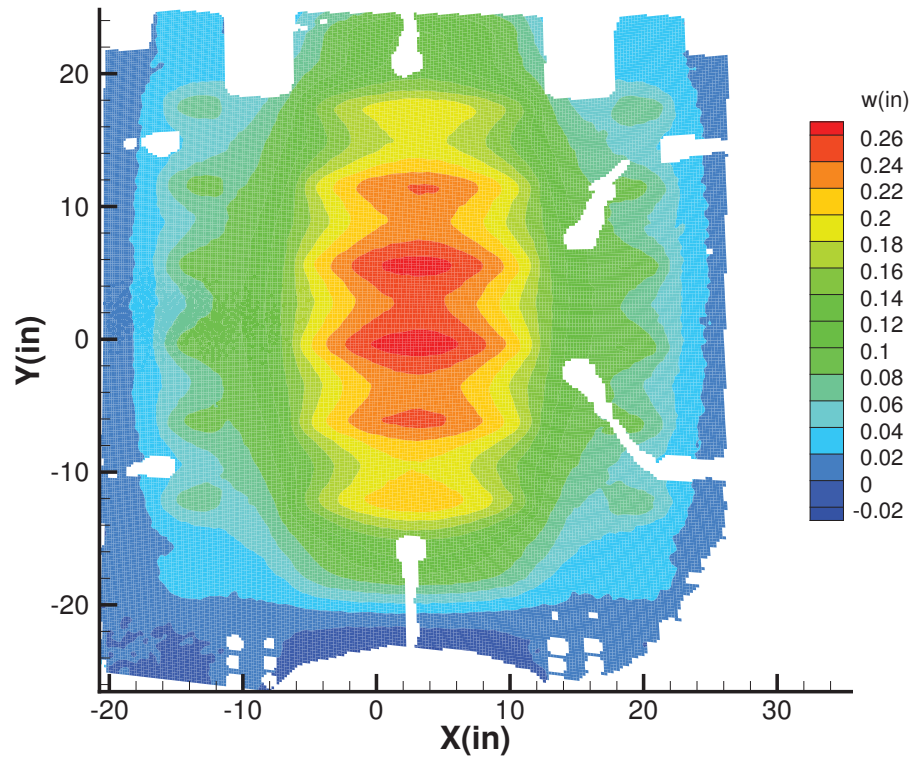


Figure 36. VIC normal displacement plot for speckled rib at 18.4 psi (2P). White spaces indicate areas where VIC data was not recorded.

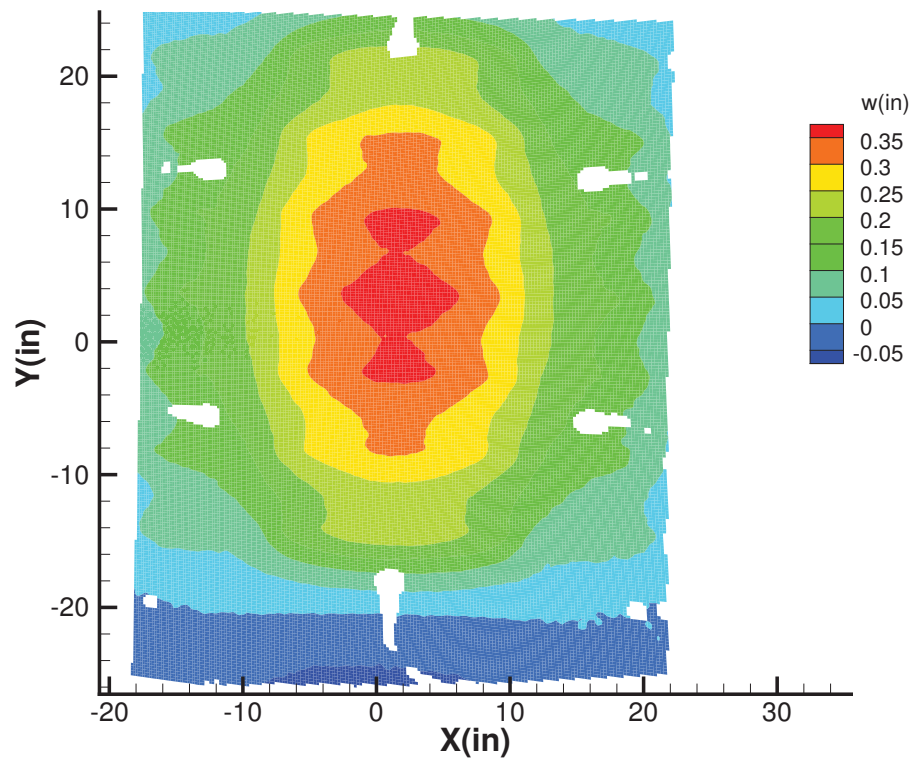


Figure 37. VIC normal displacement plot for speckled bulkhead at 18.4 psi (2P). White spaces indicate areas where VIC data was not recorded.

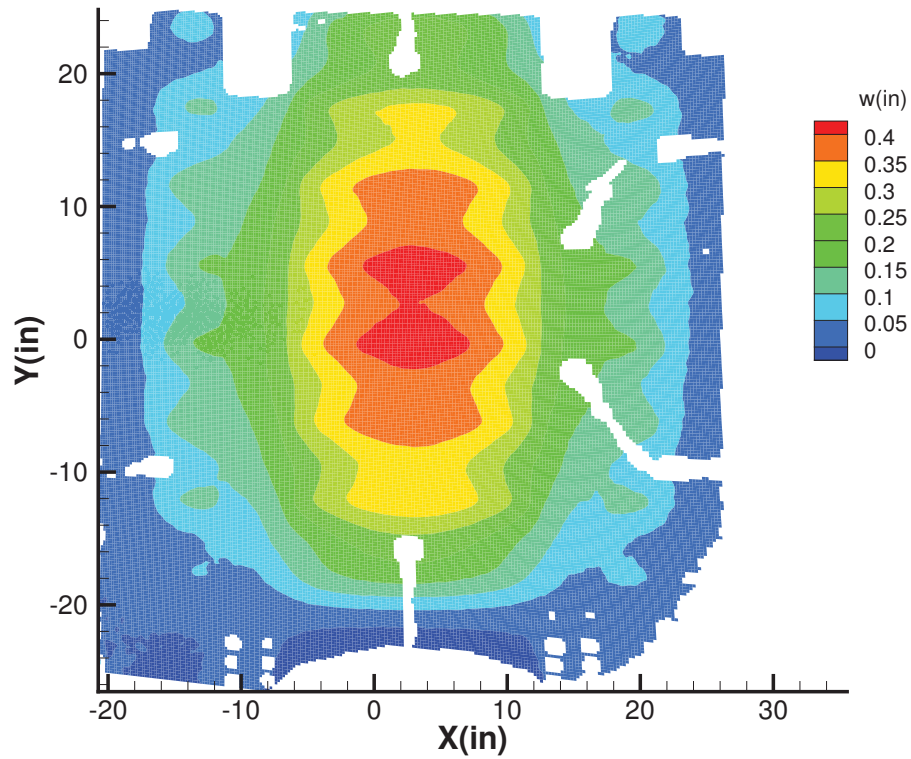


Figure 38. VIC normal displacement plot for speckled rib at 30.0 psi. White spaces indicate areas where VIC data not recorded.

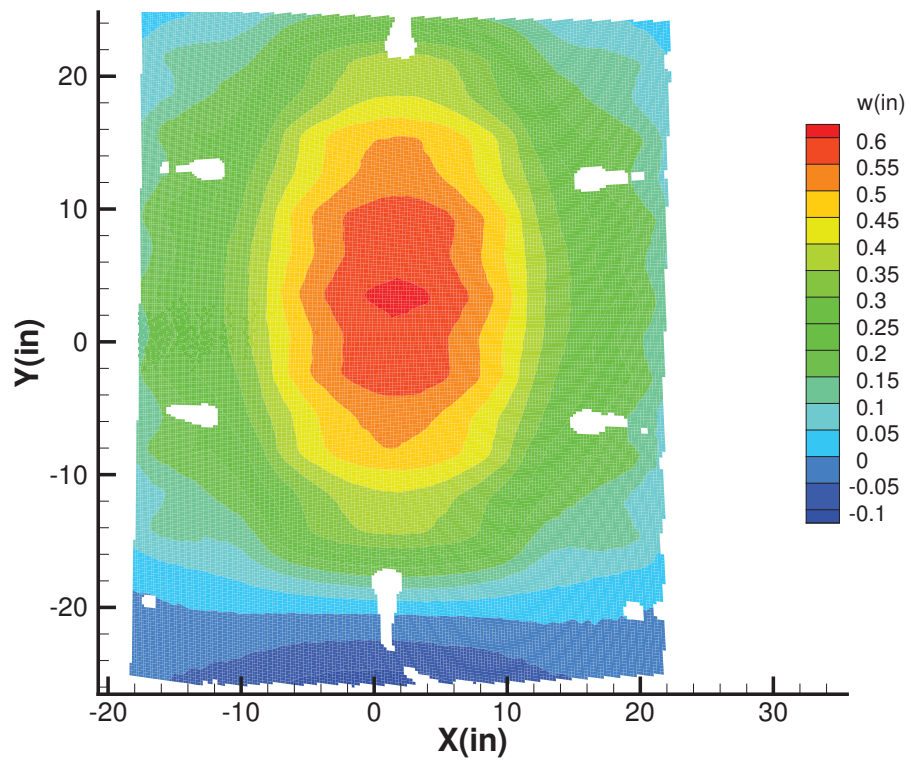


Figure 39. VIC normal displacement plot for speckled bulkhead at 30.0 psi. White spaces indicate areas where VIC data was not recorded.



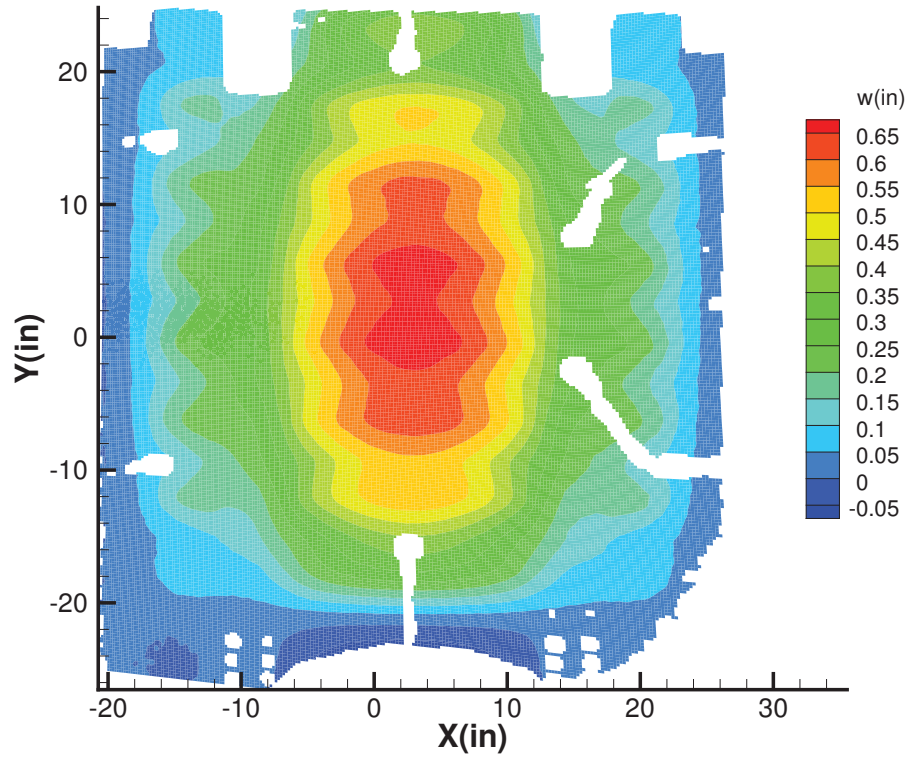


Figure 40. VIC normal displacement plot for speckled rib just prior to catastrophic failure, approximately 48 psi. White spaces indicate areas where VIC data not recorded.

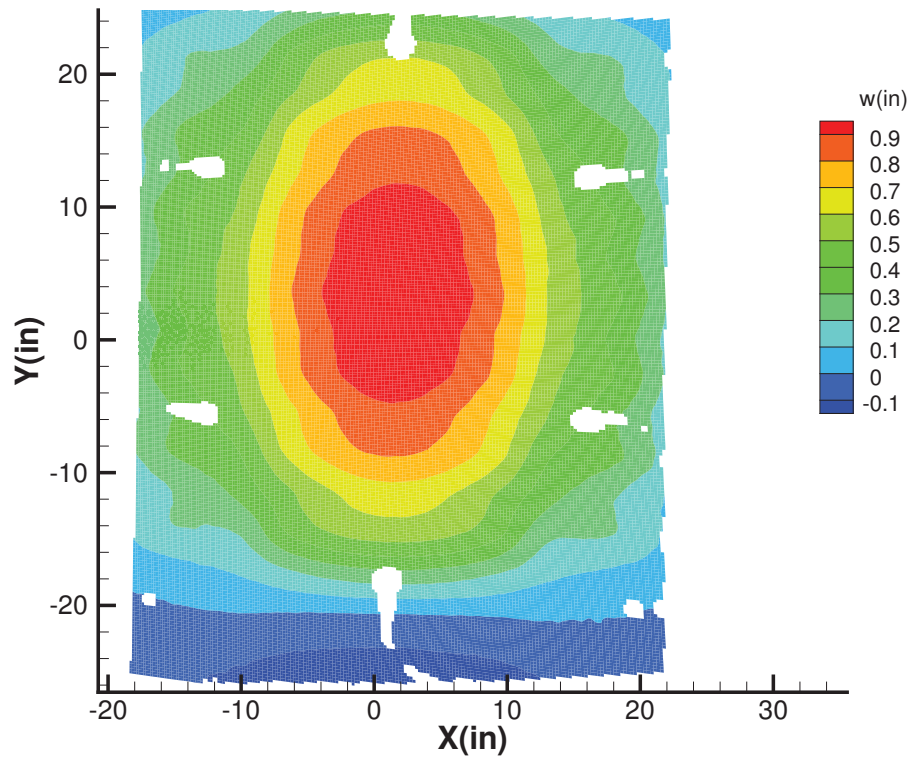


Figure 41. VIC normal displacement plot for speckled bulkhead just prior to catastrophic failure, approximately 48 psi. White spaces indicate areas where VIC data was not recorded.

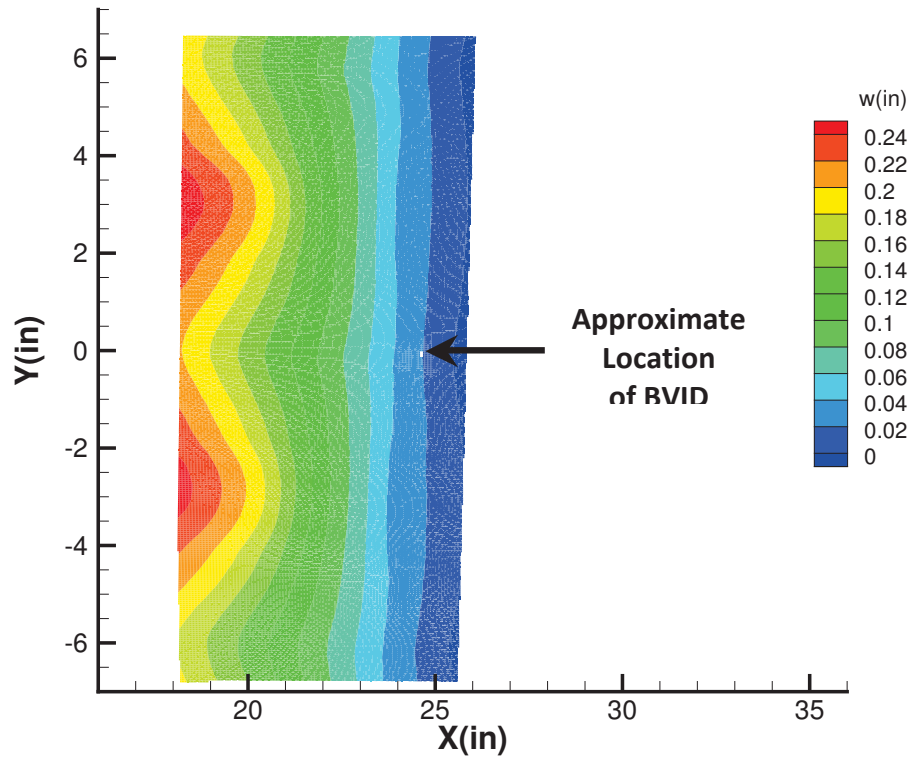


Figure 42. VIC normal displacement plot of rib BVID location just prior to catastrophic failure, approximately 48 psi. White spaces indicate areas where VIC data was not recorded.

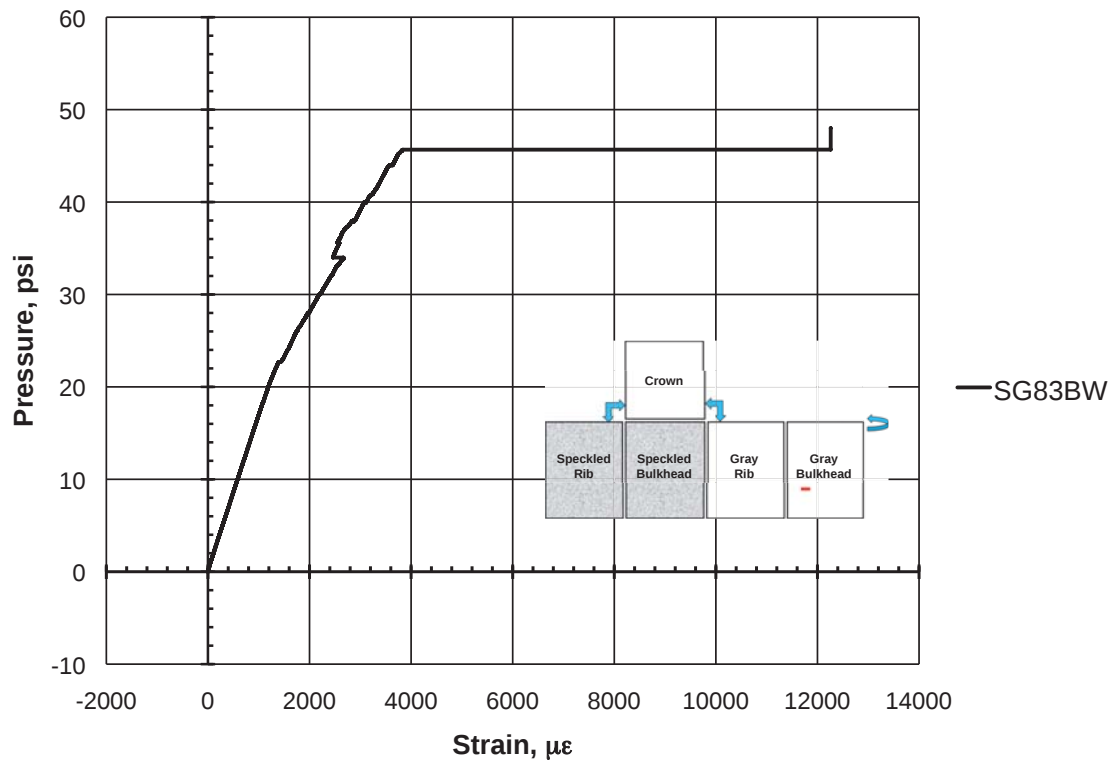


Figure 43. Response of strain gage SG83BW (IML, inside frame web keyhole beside rod, parallel to frame height) for loading up to catastrophic failure.

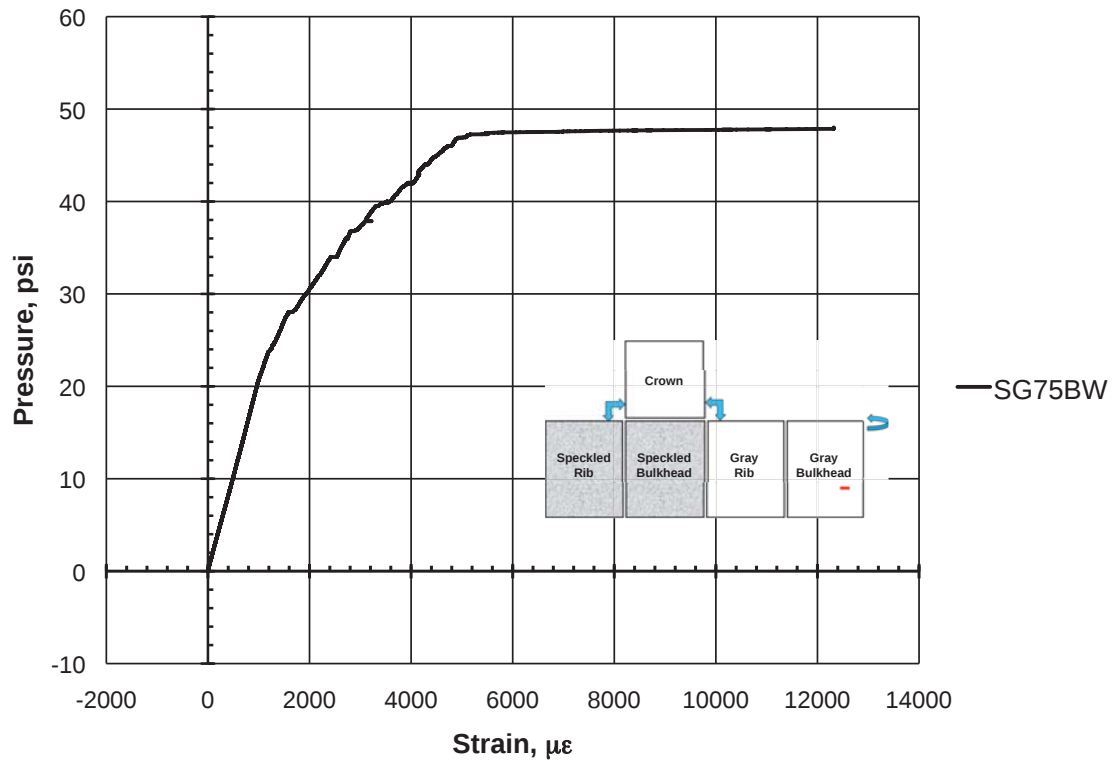


Figure 44. Response of strain gage SG75BW (IML, inside frame web keyhole beside rod, parallel to frame height) for loading up to catastrophic failure.

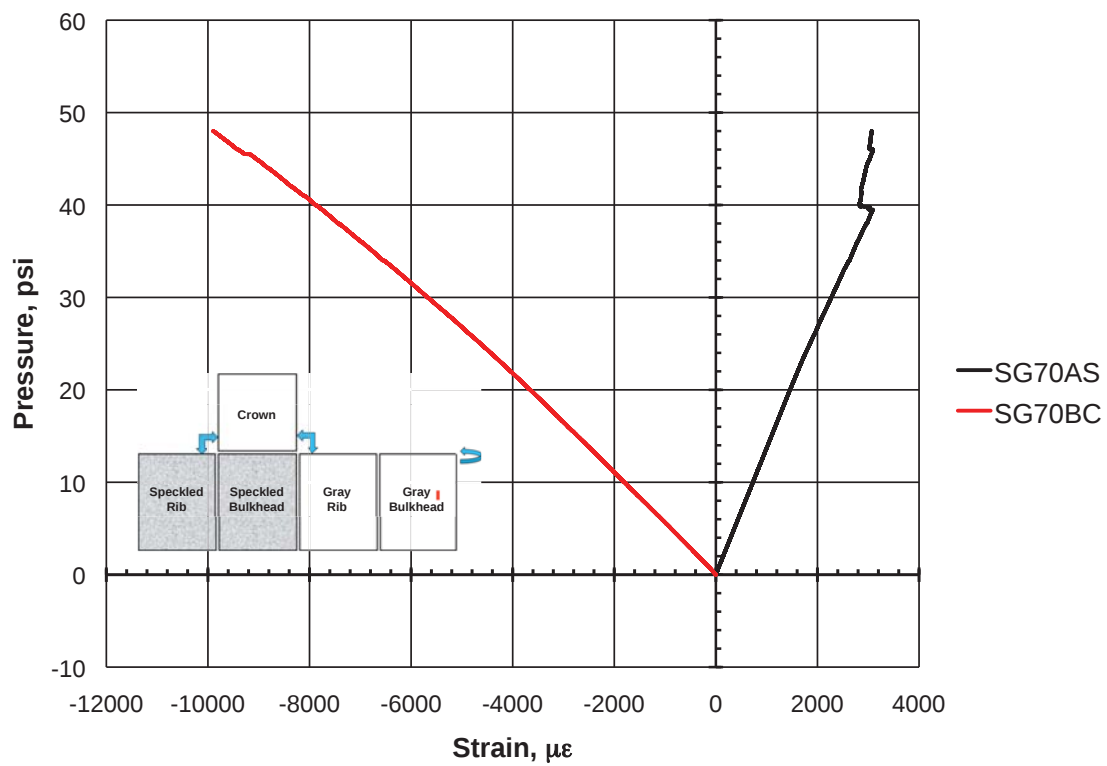


Figure 45. Response of strain gages SG70AS (OML) and SG70BC (IML, frame cap) for loading up to catastrophic failure.

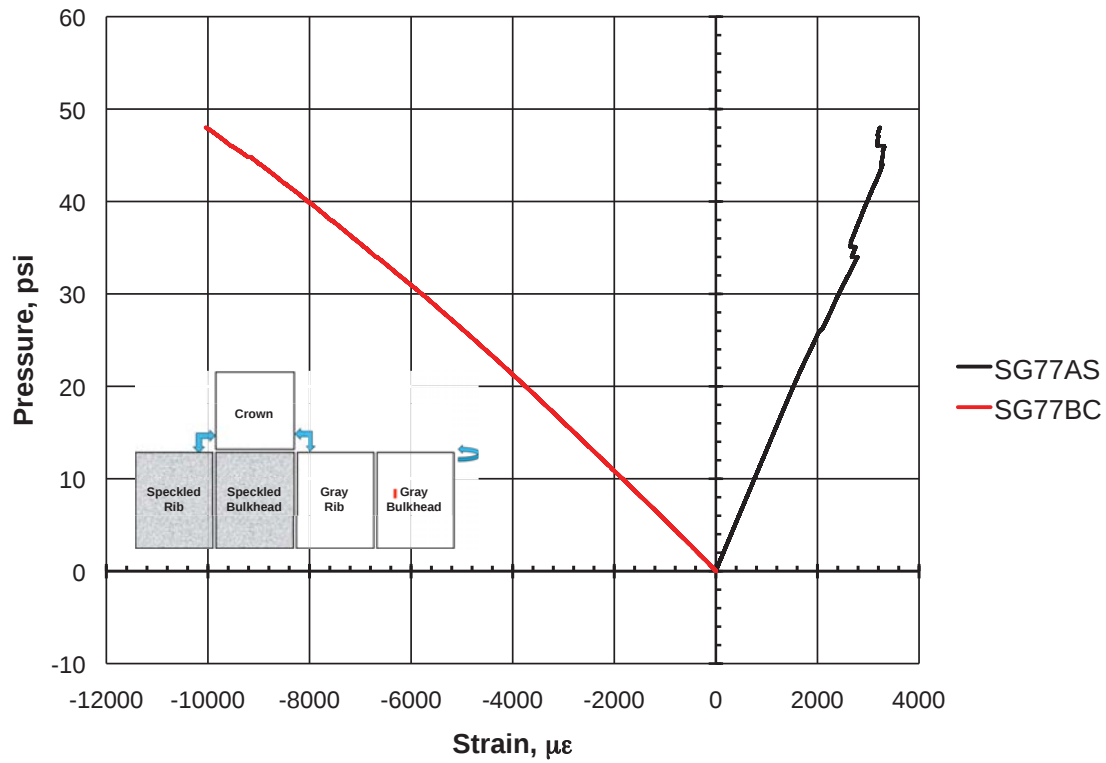


Figure 46. Response of strain gages SG77AS (OML) and SG77BC (IML, frame cap) for loading up to catastrophic failure.

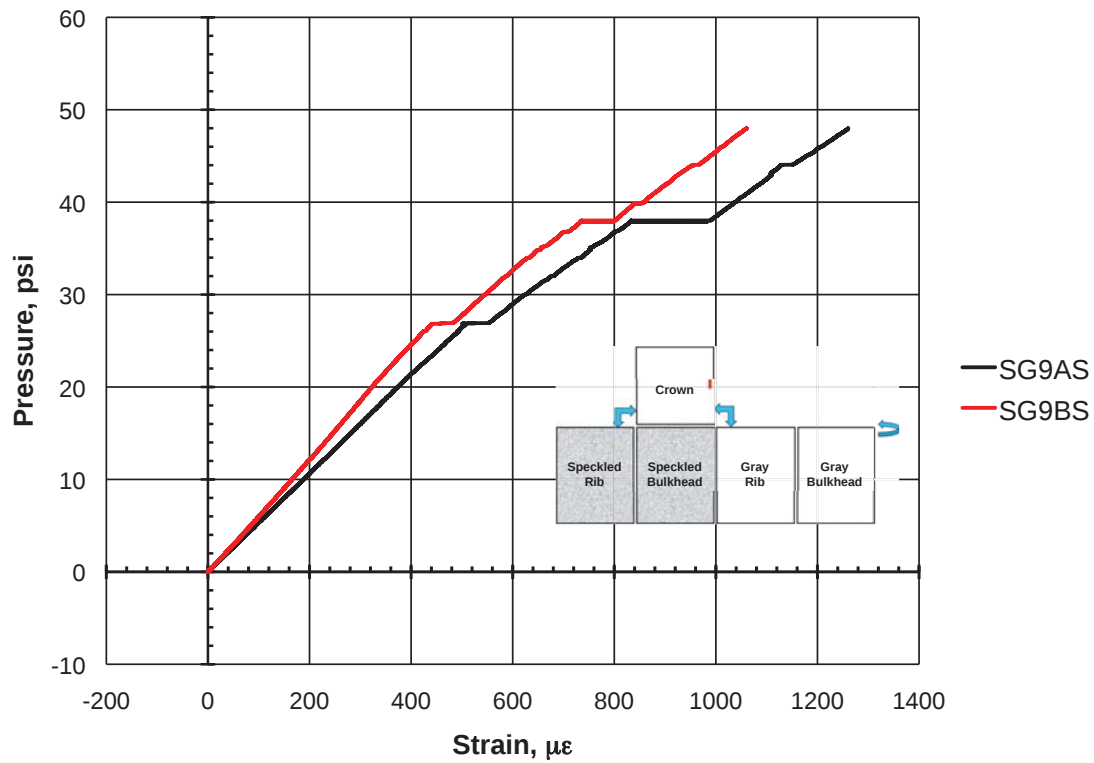


Figure 47. Response of strain gages SG9AS (OML) and SG9BS (IML) for loading up to catastrophic failure.



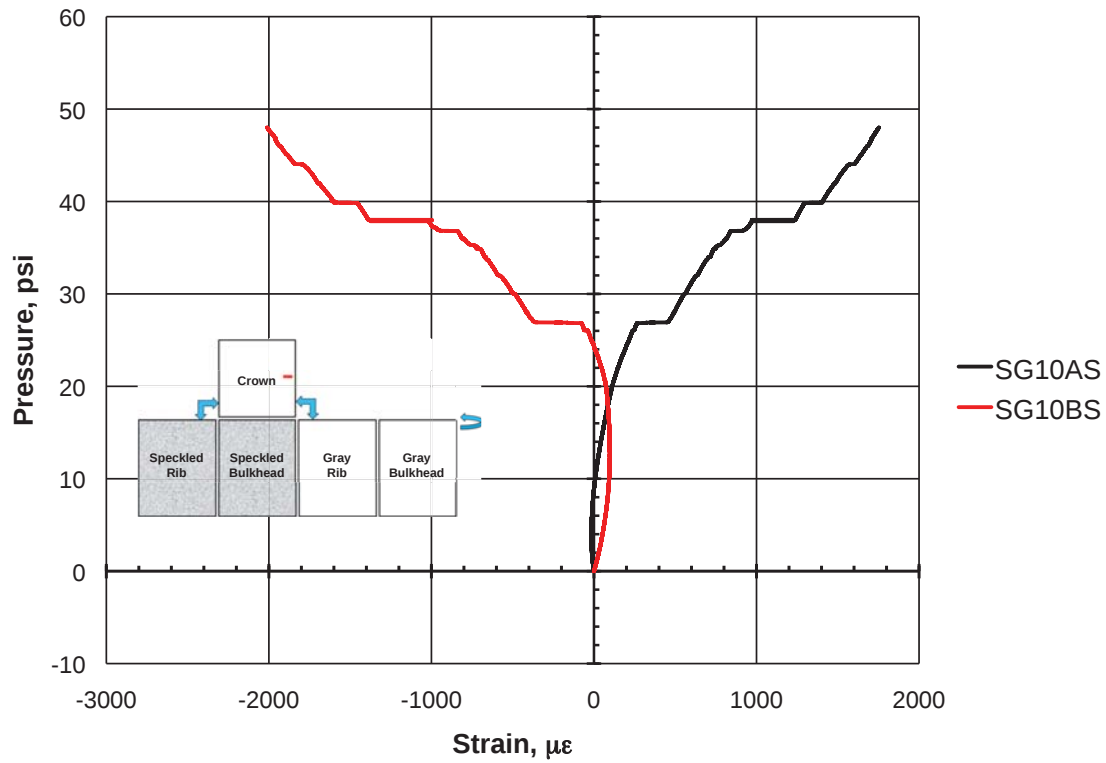


Figure 48. Response of strain gauges SG10AS (OML) and SG10BS (IML) for loading up to catastrophic failure.

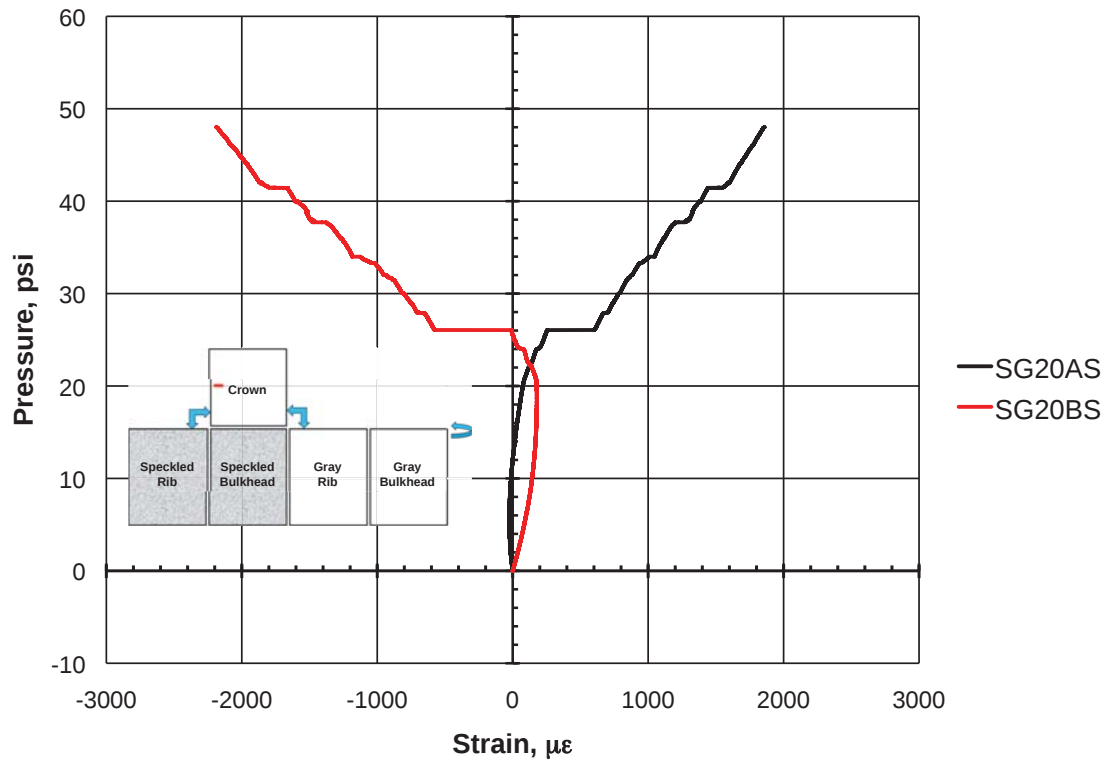


Figure 49. Response of strain gauges SG20AS (OML) and SG20BS (IML) for loading up to catastrophic failure.

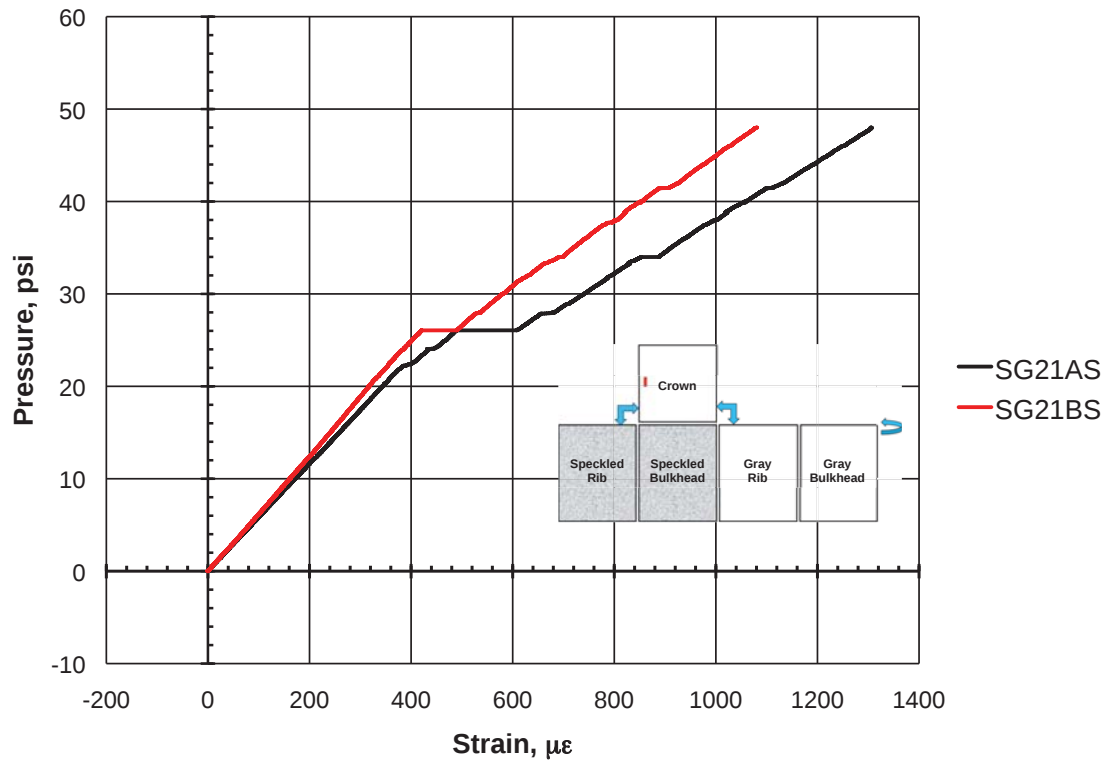


Figure 50. Response of strain gages SG21AS (OML) and SG21BS (IML) for loading up to catastrophic failure.

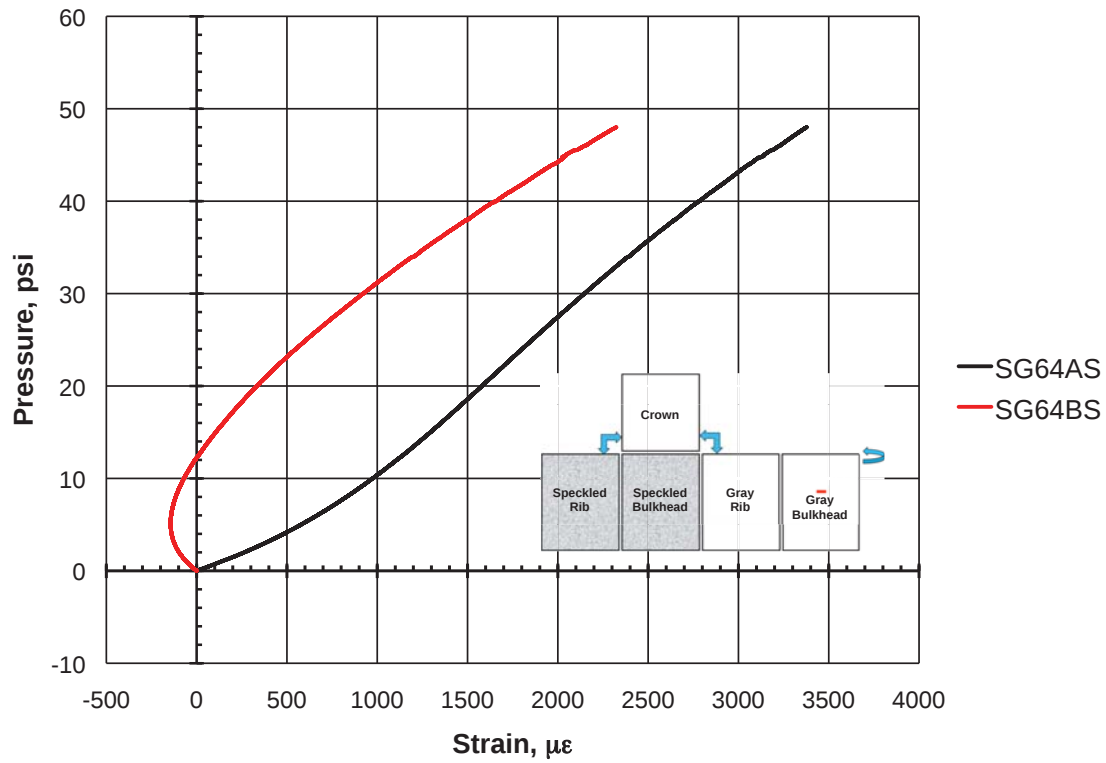


Figure 51. Response of strain gages SG64AS (OML) and SG64BS (IML) for loading up to catastrophic failure.

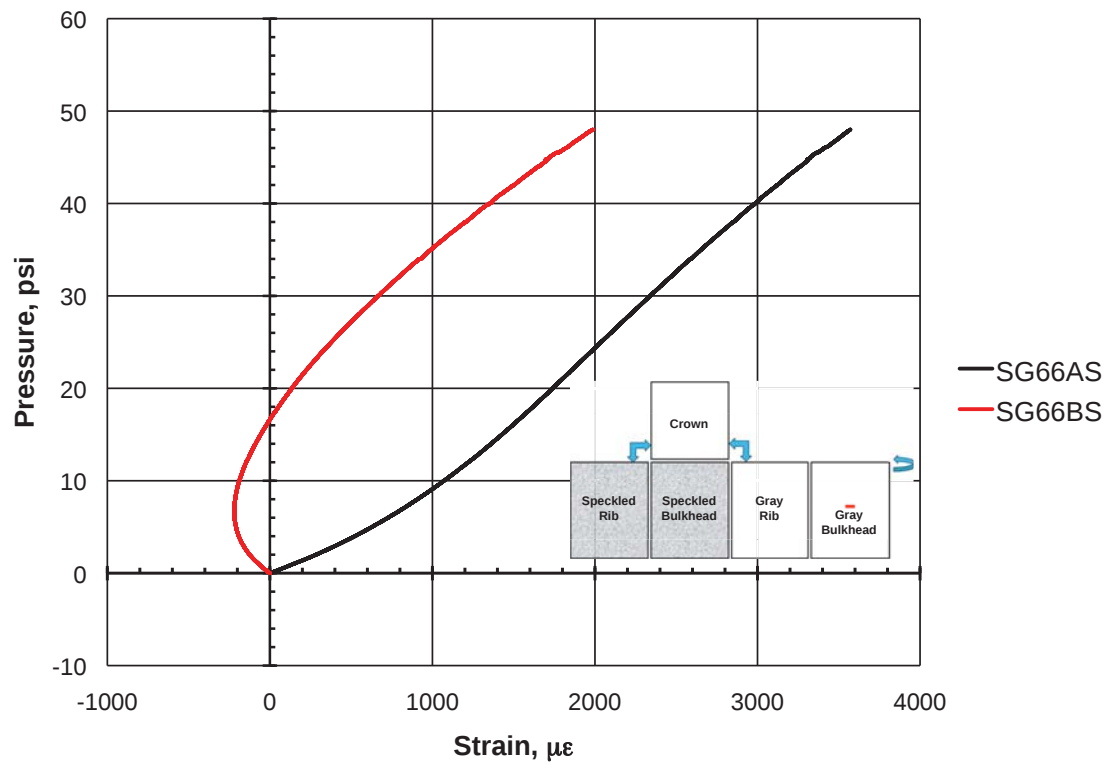


Figure 52. Response of strain gages SG66AS (OML) and SG66BS (IML) for loading up to catastrophic failure.

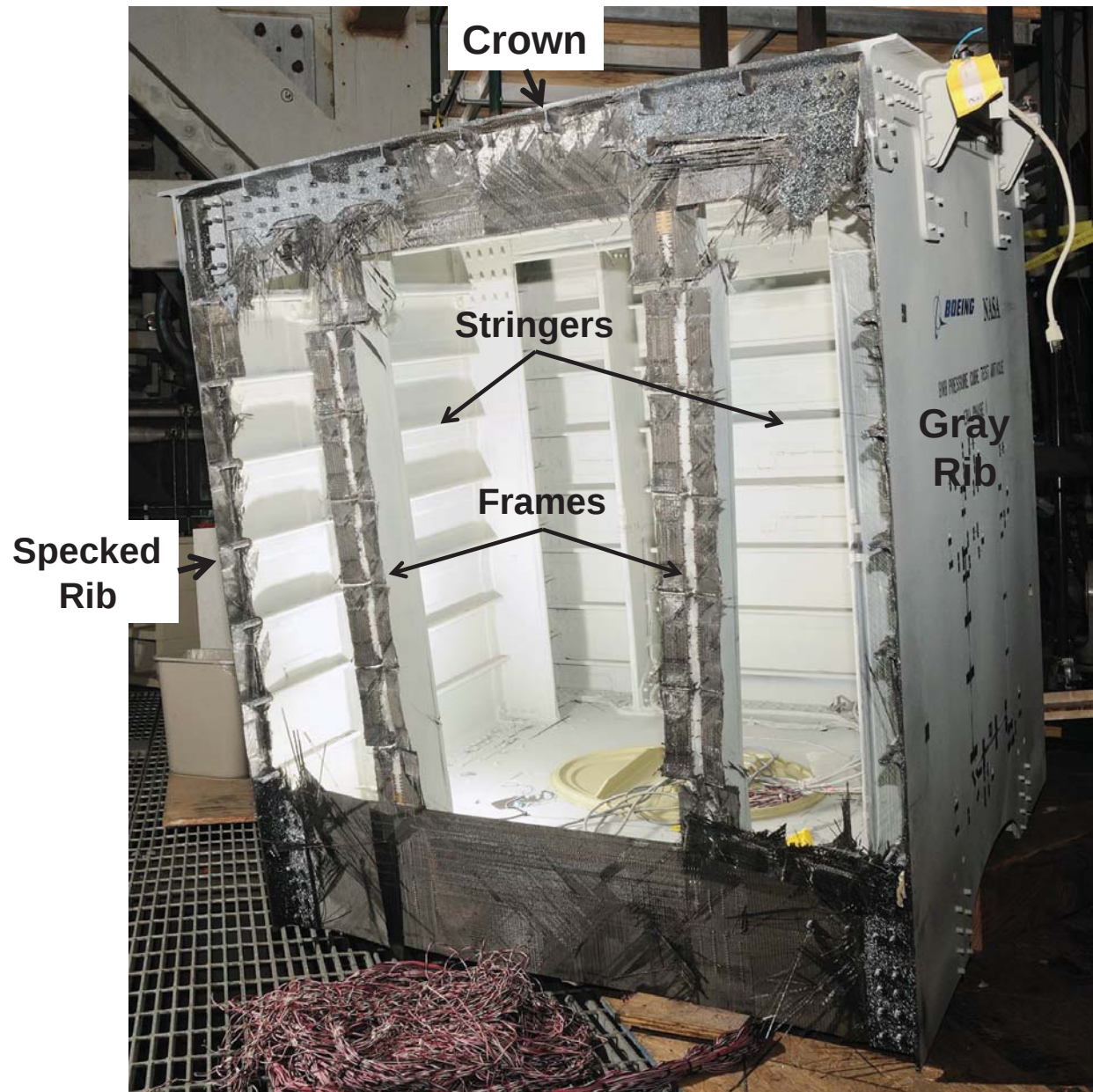


Figure 53. Failed pressure cube, speckled bulkhead panel blown off.



a) Location of failed fitting in cube, crown frame to speckled rib frame



b) Outside fitting



c) Inside fitting

Figure 54. Failed frame attachment fitting between crown and speckled rib in pressure cube.



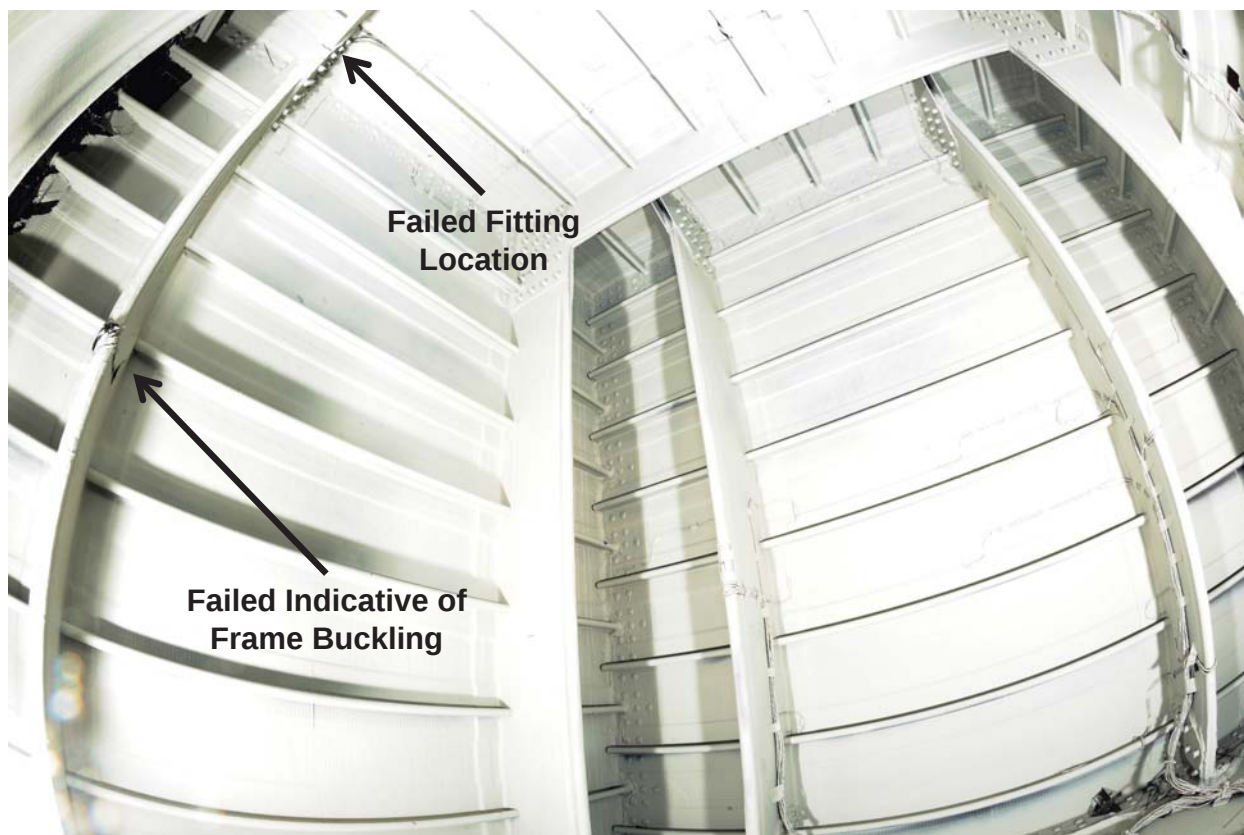
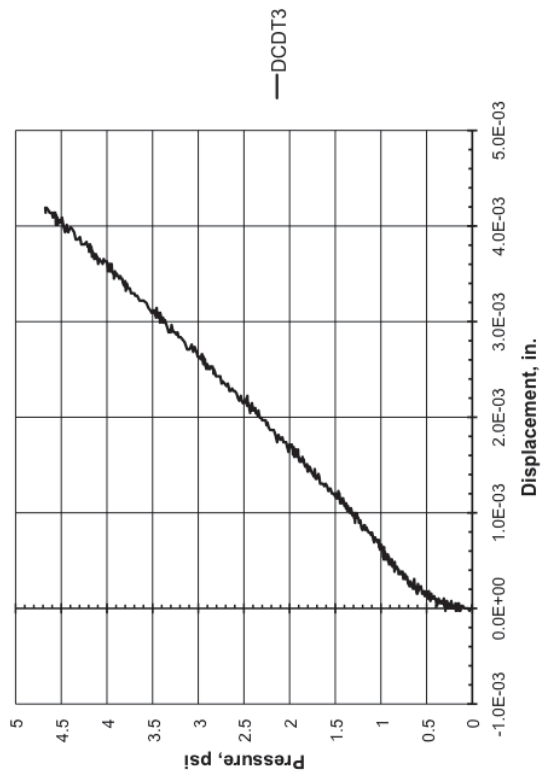
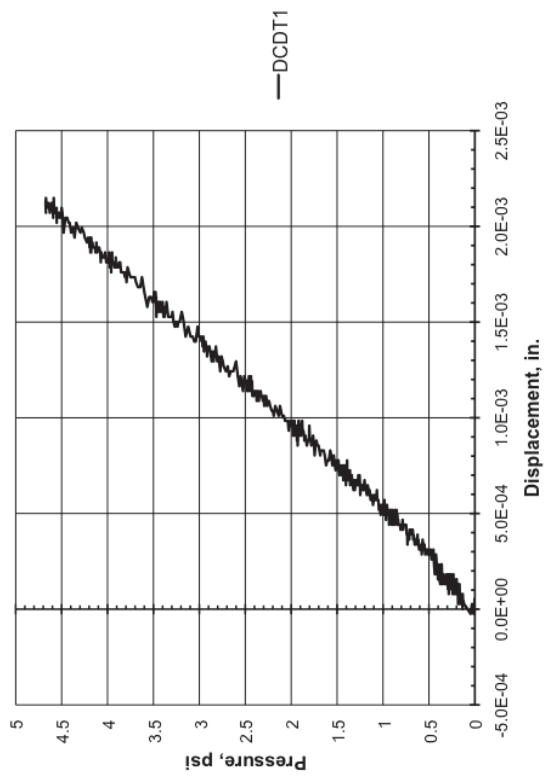


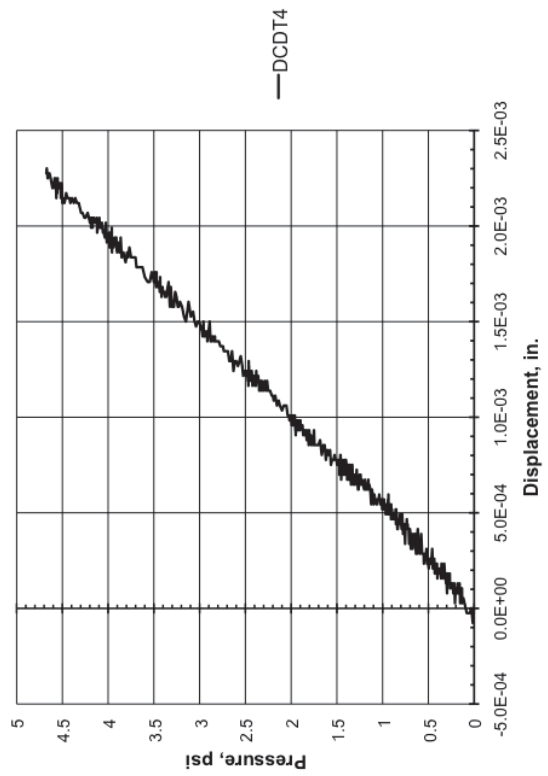
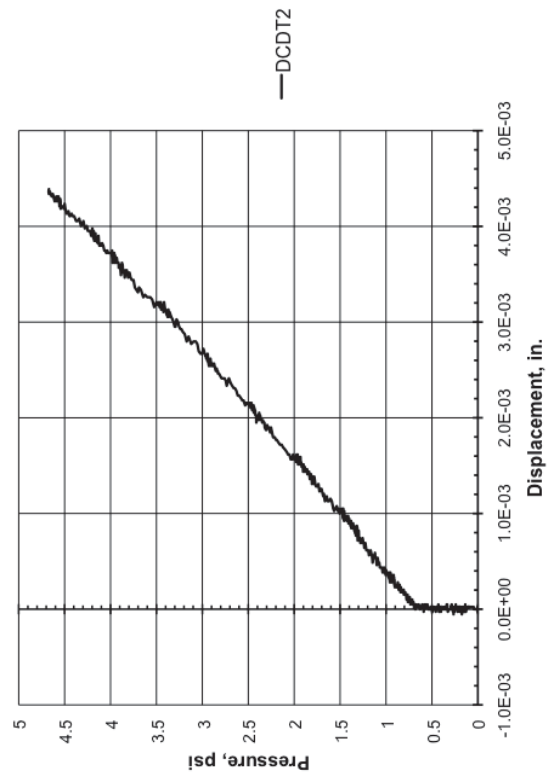
Figure 55. Indication of local buckling of speckled rib frame attached to the failed frame fitting.



**Appendix A:**  
**Checkout Test 1 DCDT and Strain Gage Plots**



A2



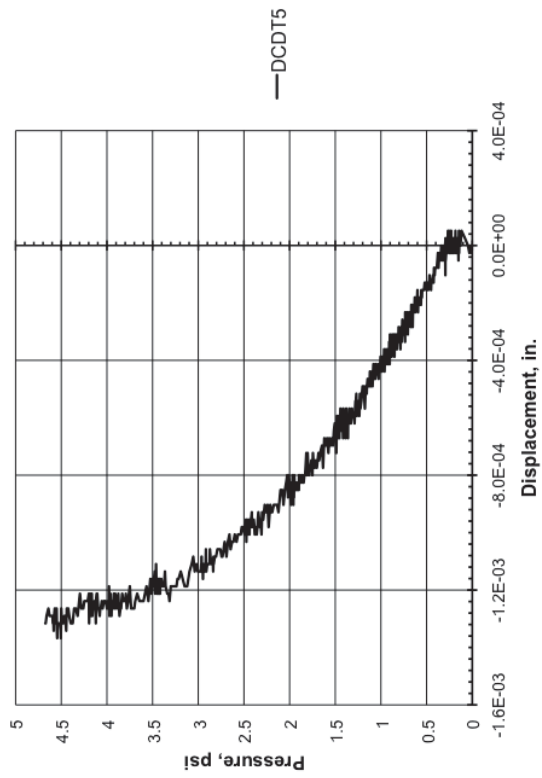


Figure A5. Checkout test 1, DCDT5.

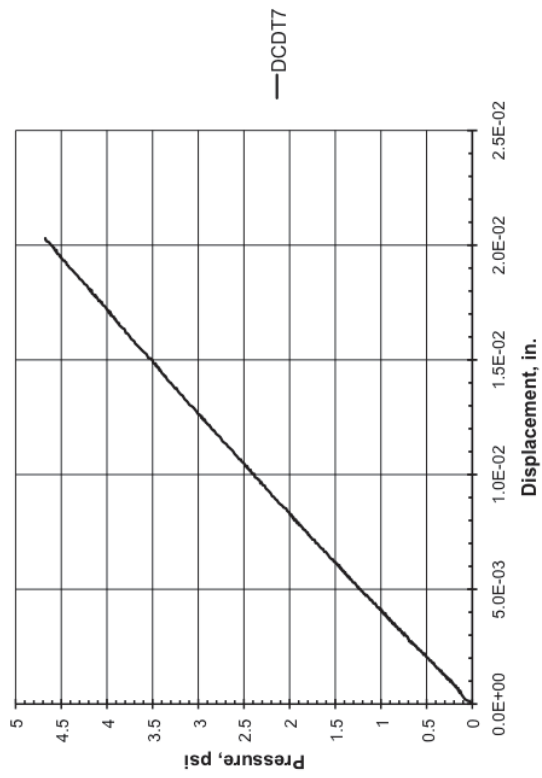


Figure A7. Checkout test 1, DCDT7.

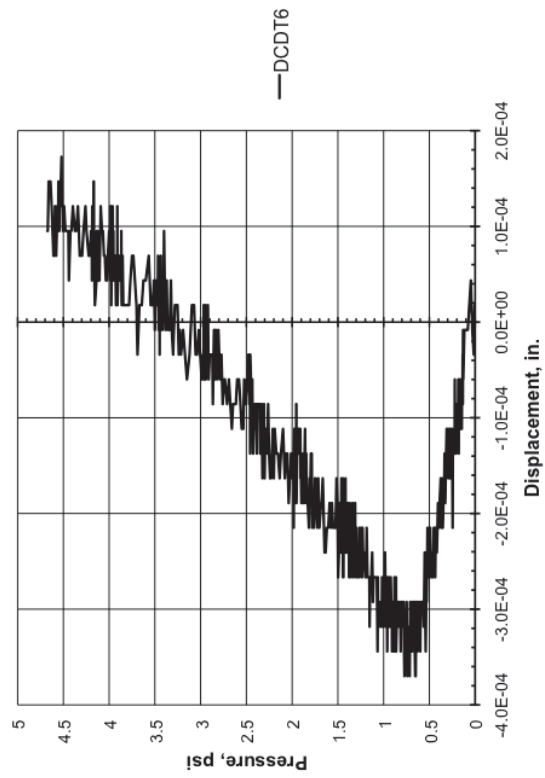


Figure A6. Checkout test 1, DCDT6.

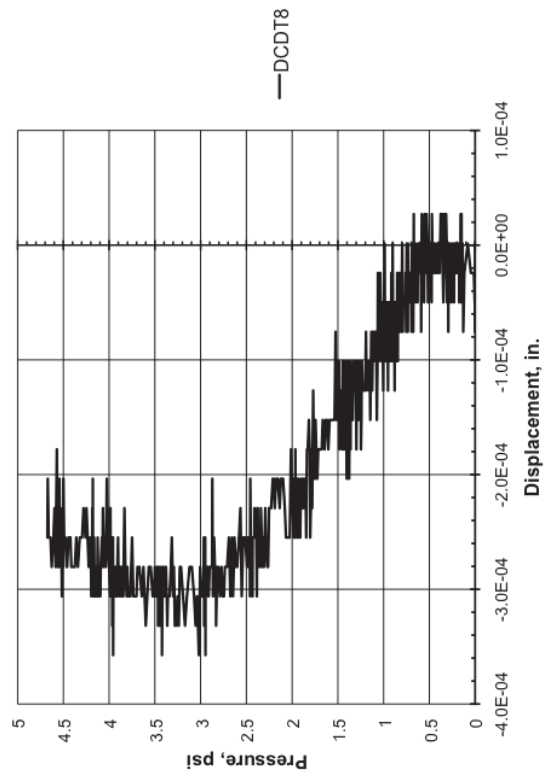


Figure A8. Checkout test 1, DCDT8.

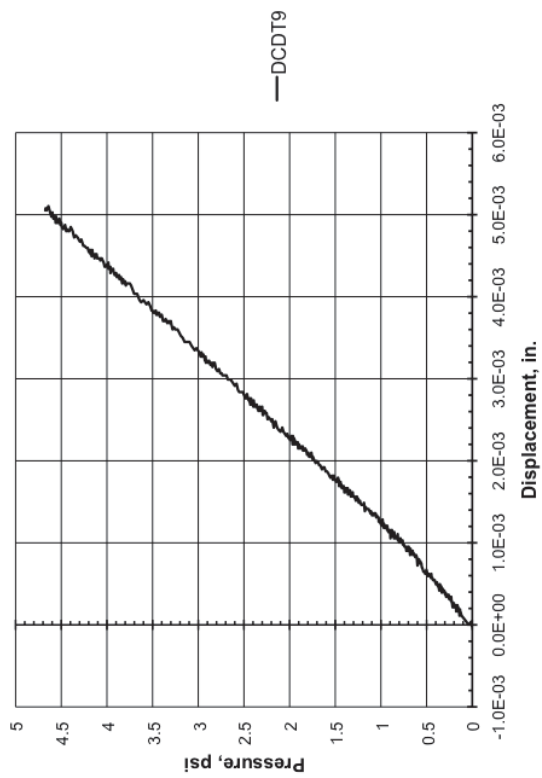


Figure A9. Checkout test 1, DCDT9.

A4

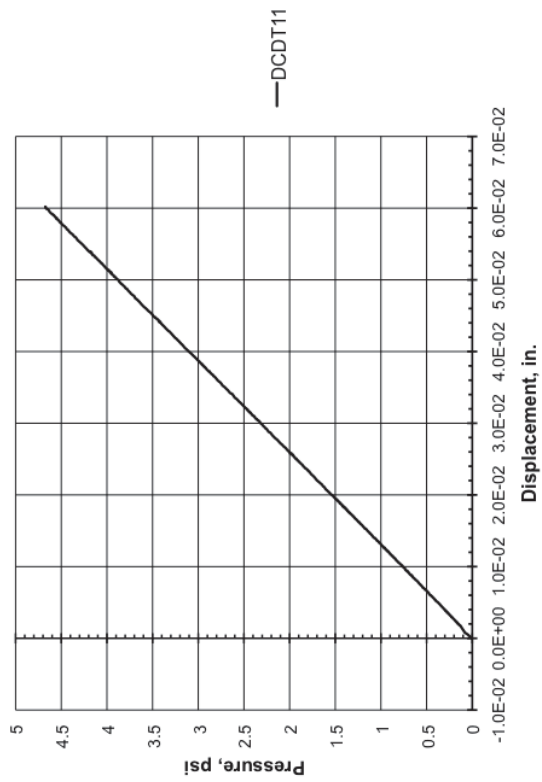


Figure A11. Checkout test 1, DCDT11.

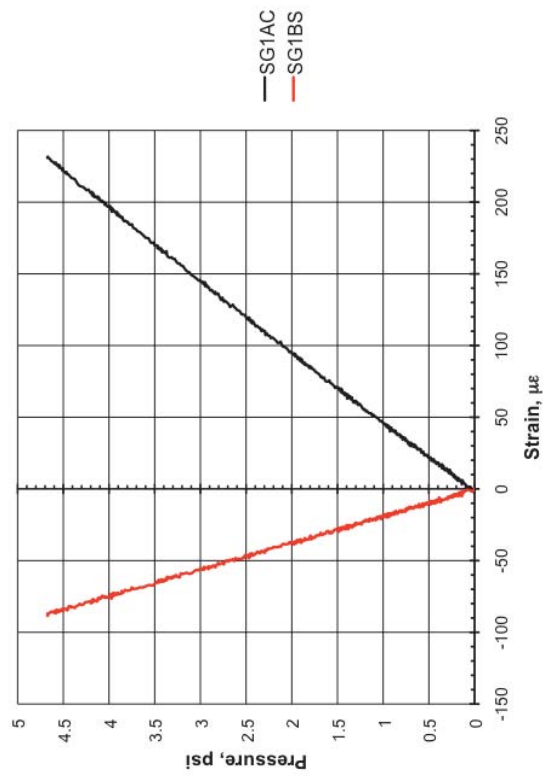


Figure A12. Checkout test 1, strain gages SG1AC and SG1BS.

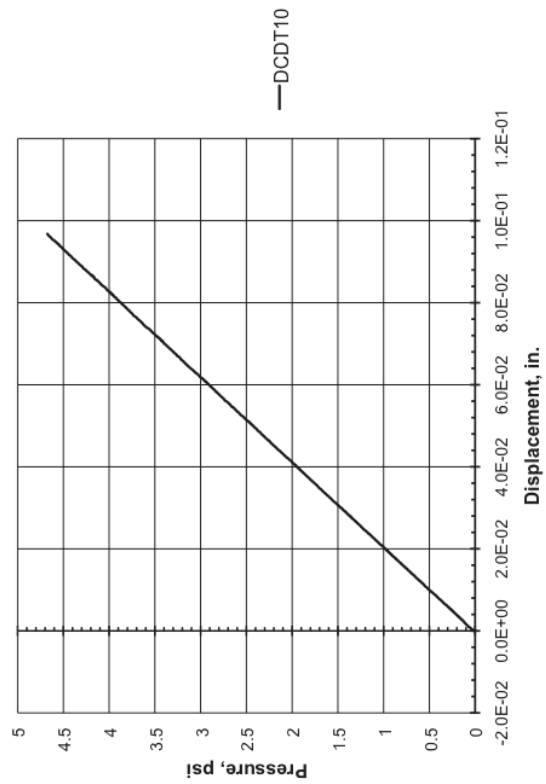


Figure A10. Checkout test 1, DCDT10.

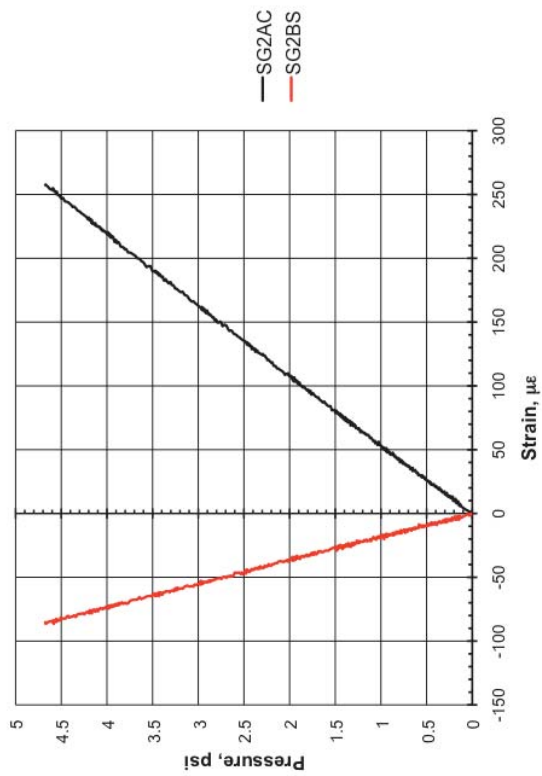


Figure A13. Checkout test 1, strain gages SG2AC and SG2BS.

A5

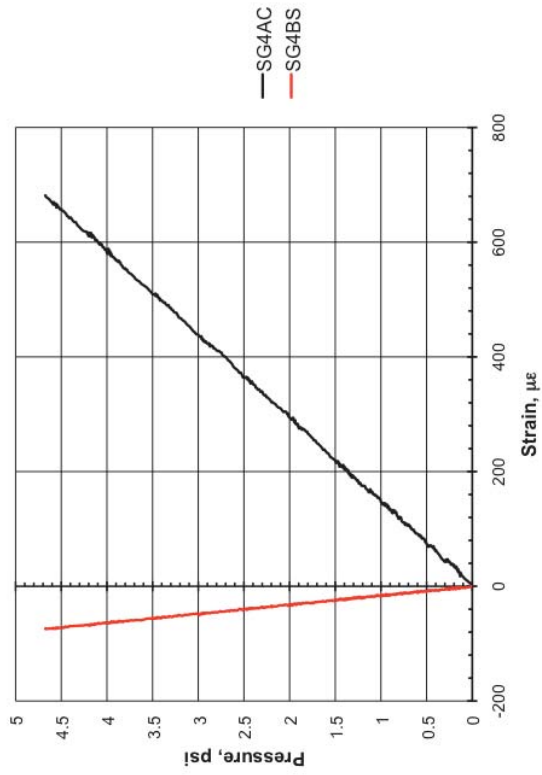


Figure A15. Checkout test 1, strain gages SG4AC and SG4BS.

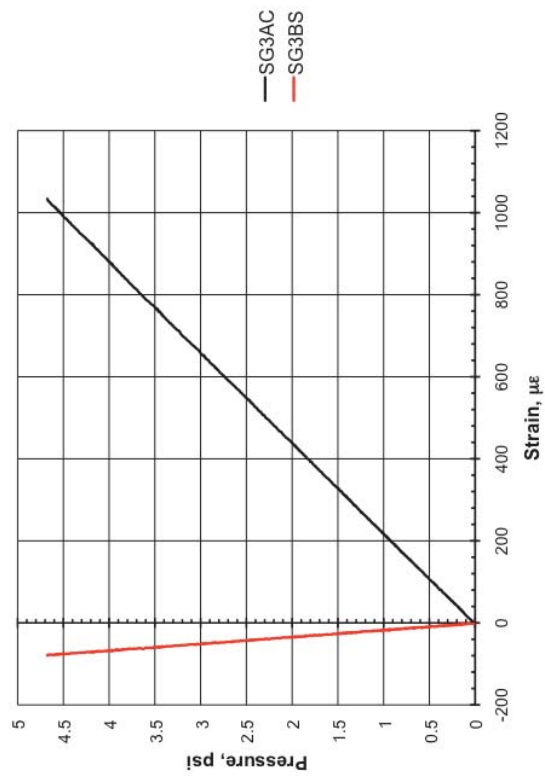


Figure A14. Checkout test 1, strain gages SG3AC and SG3BS.

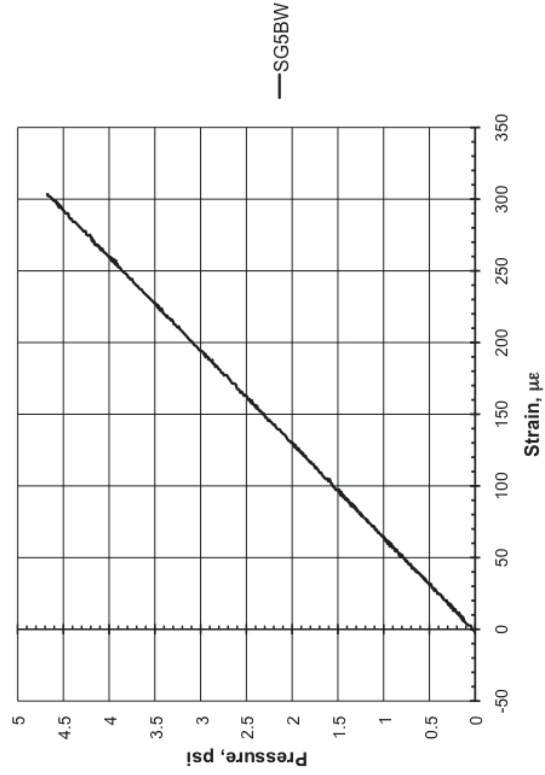


Figure A16. Checkout test 1, strain gage SG5BW.

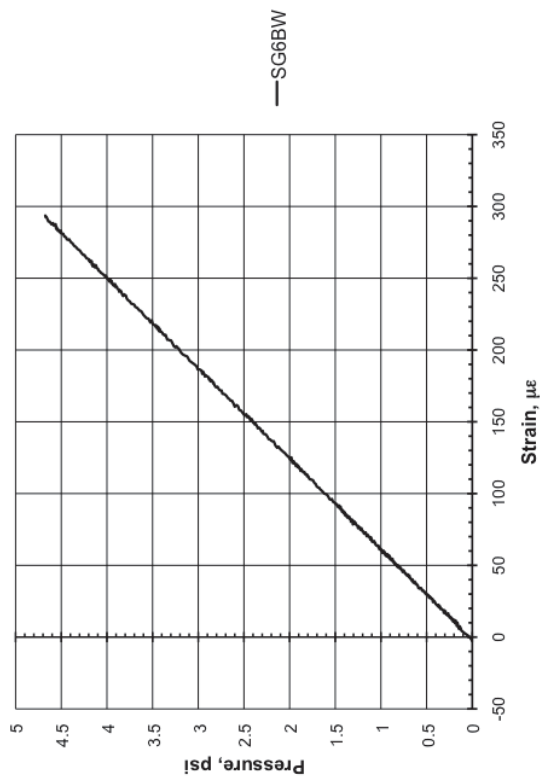


Figure A17. Checkout test 1, strain gage SG6BW.

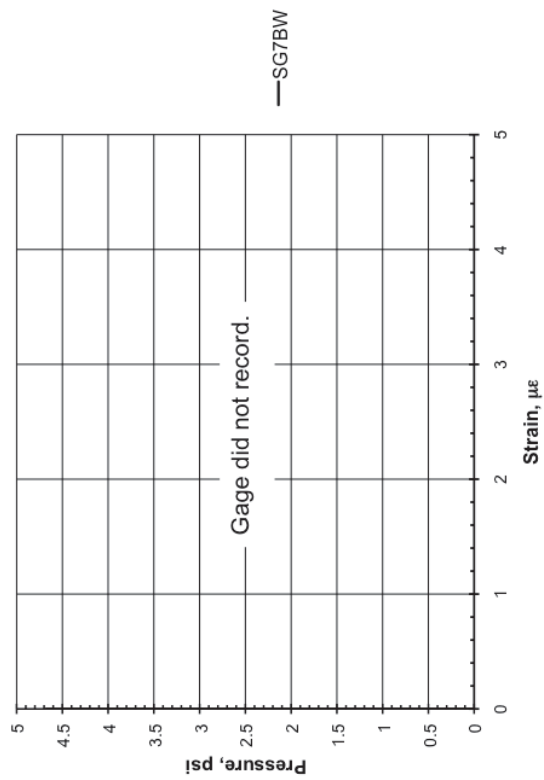


Figure A18. Checkout test 1, strain gage SG7BW.

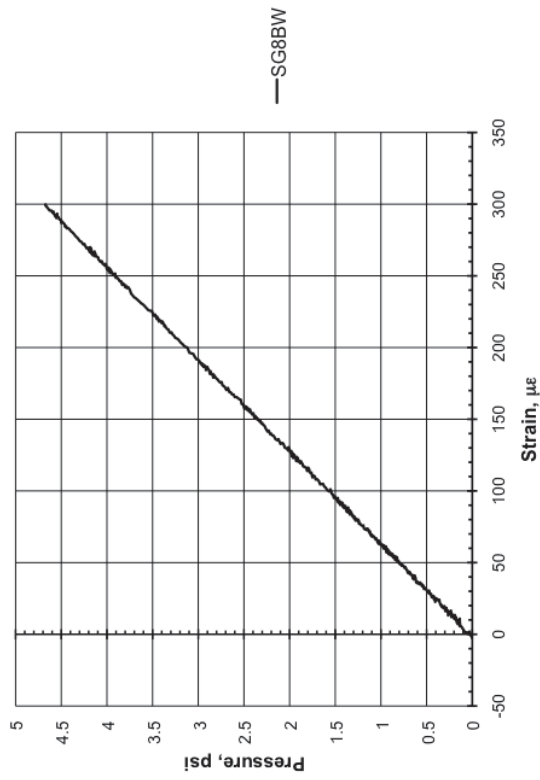


Figure A19. Checkout test 1, strain gage SG8BW.

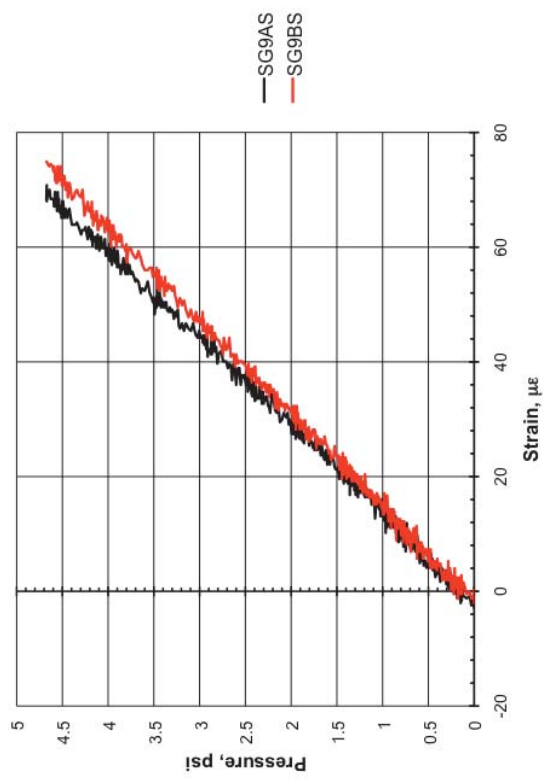


Figure A20. Checkout test 1, strain gages SG9AS and SG9BS.



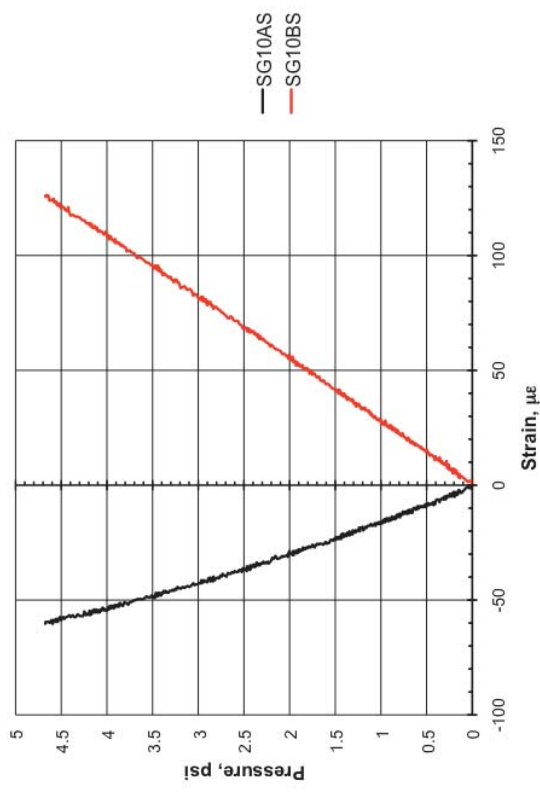


Figure A21. Checkout test 1, strain gages SG10AS and SG10BS.

A7

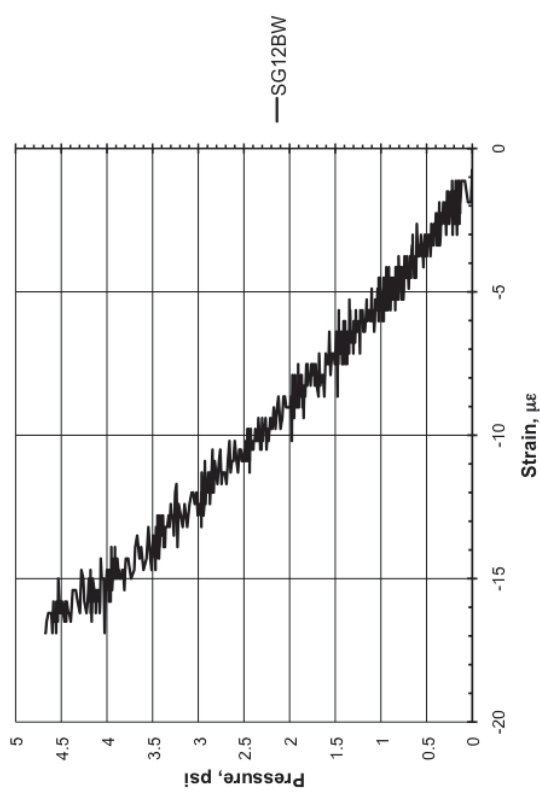


Figure A23. Checkout test 1, strain gage SG12BW.

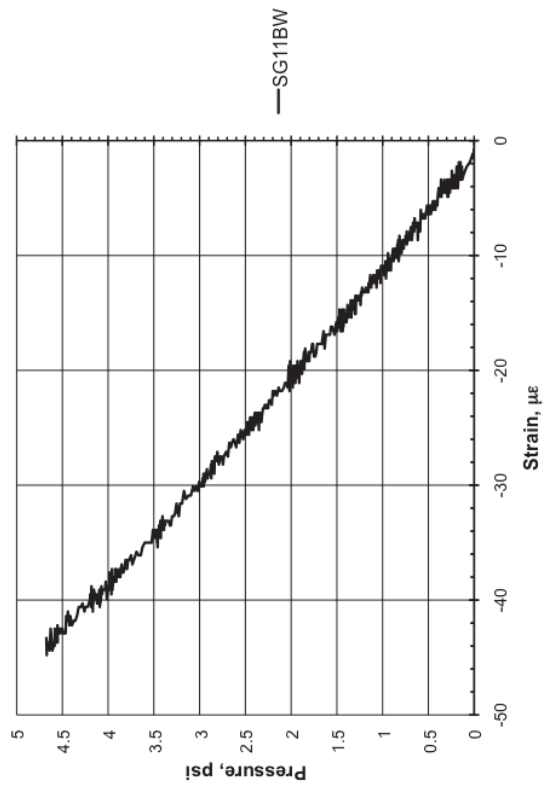


Figure A22. Checkout test 1, strain gage SG11BW.

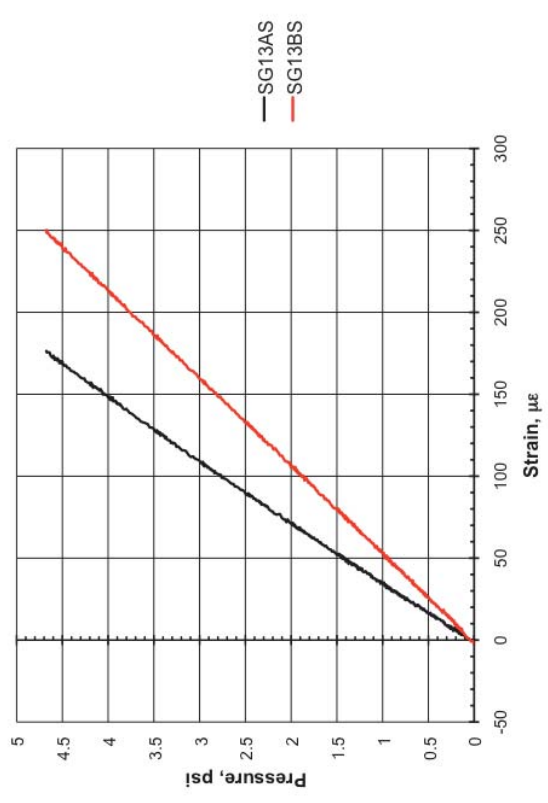


Figure A24. Checkout test 1, strain gages SG13AS and SG13BS.

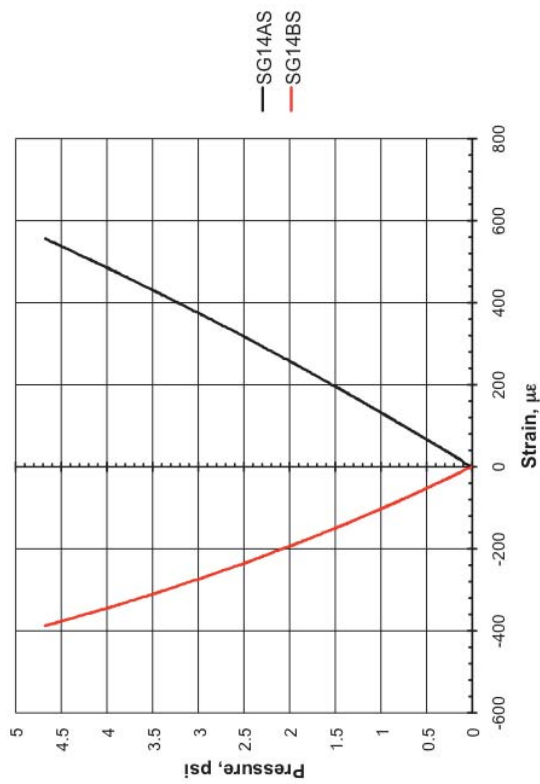


Figure A25. Checkout test 1, strain gages SG14AS and SG14BS.

A8

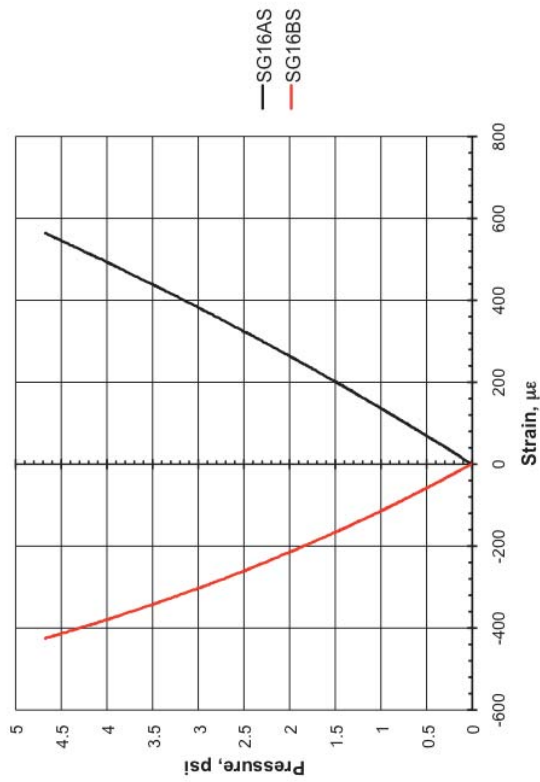


Figure A27. Checkout test 1, strain gages SG16AS and SG16BS.

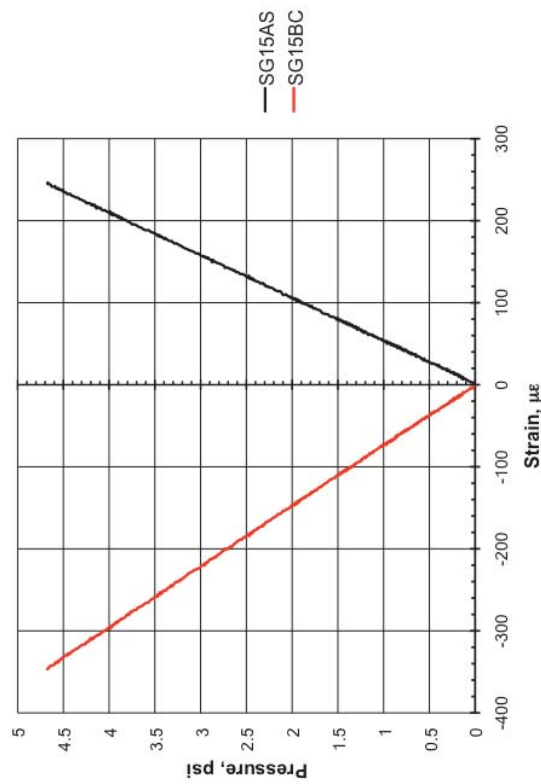


Figure A26. Checkout test 1, strain gages SG15AS and SG15BC.

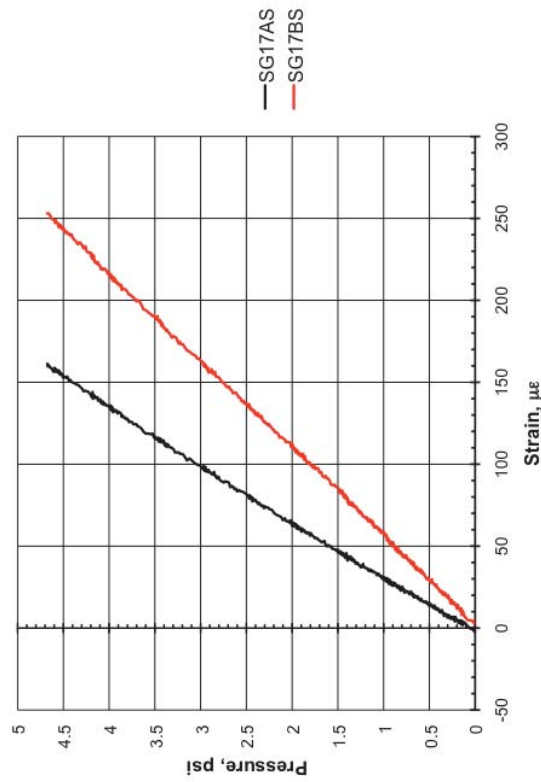


Figure A28. Checkout test 1, strain gages SG17AS and SG17BS.

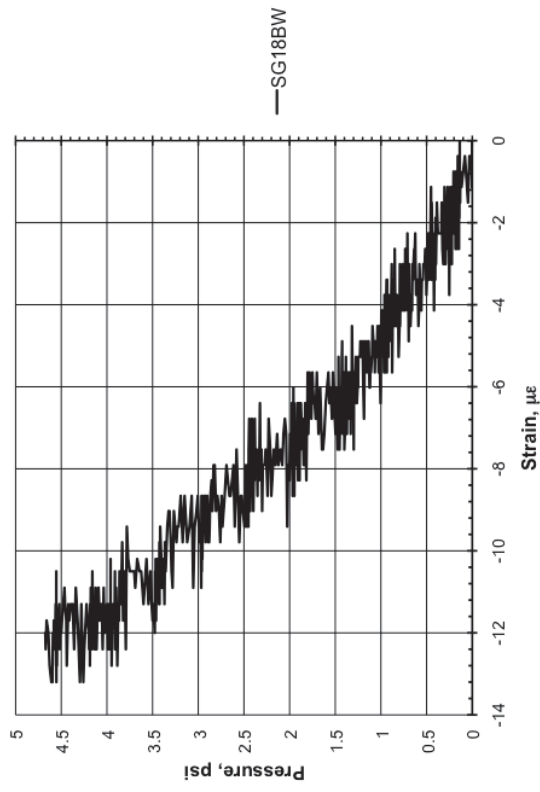


Figure A29. Checkout test 1, strain gage SG18BW.

A9

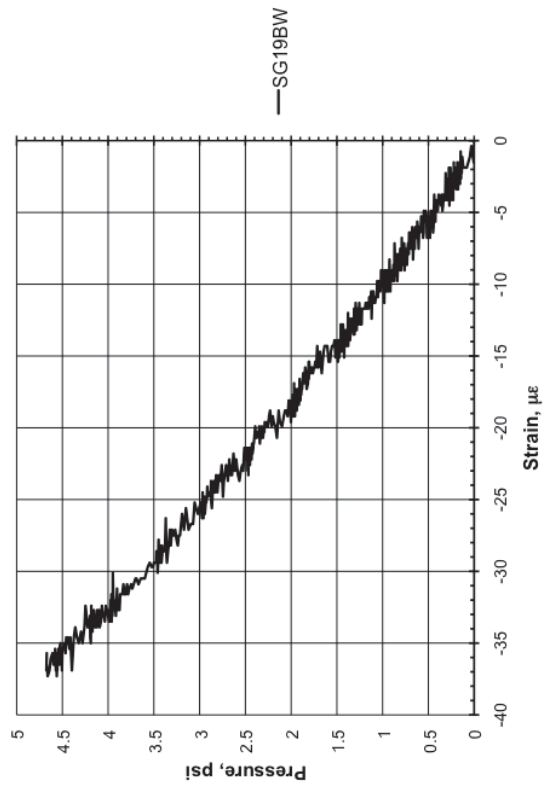


Figure A30. Checkout test 1, strain gage SG19BW.

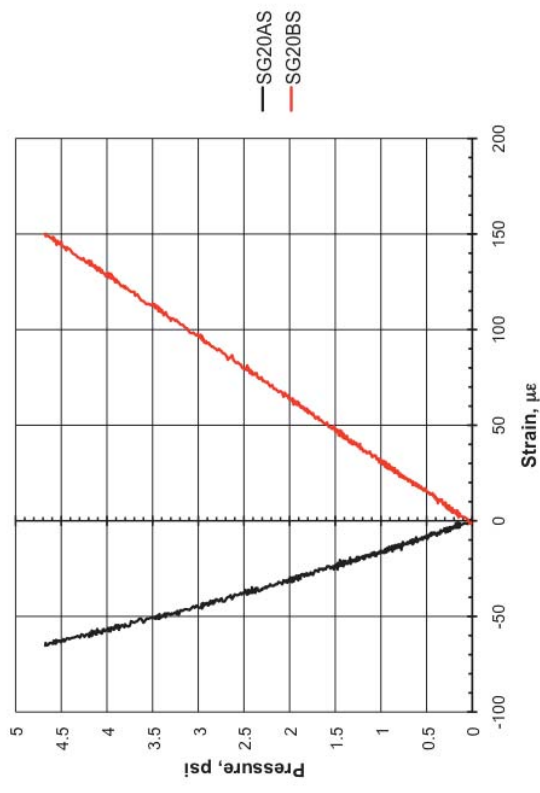


Figure A31. Checkout test 1, strain gages SG20AS and SG20BS.

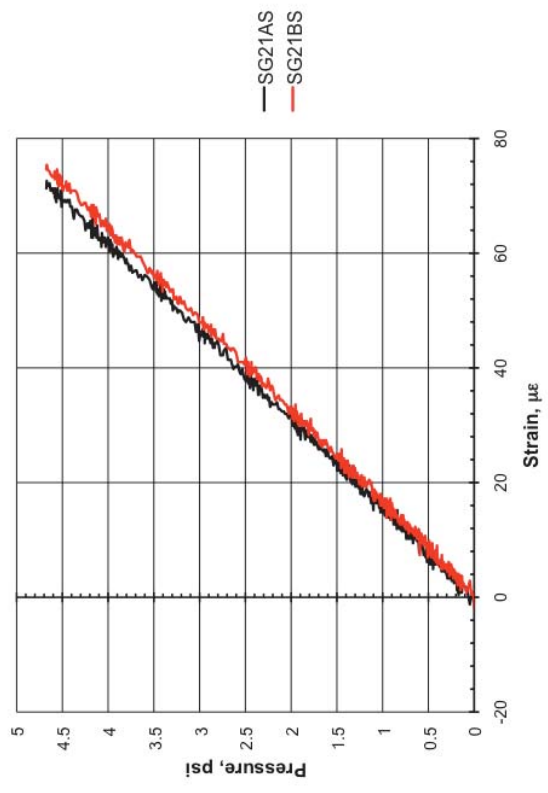


Figure A32. Checkout test 1, strain gages SG21AS and SG21BS.

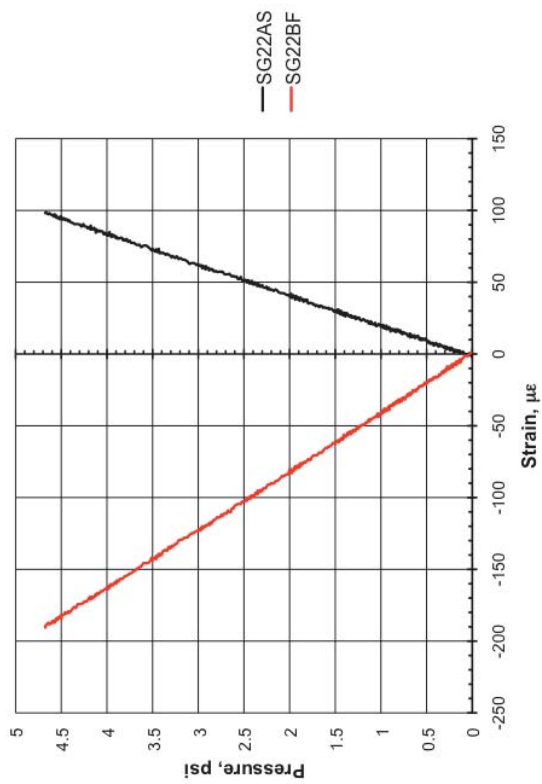


Figure A33. Checkout test 1, strain gages SG22AS and SG22BF.

A10

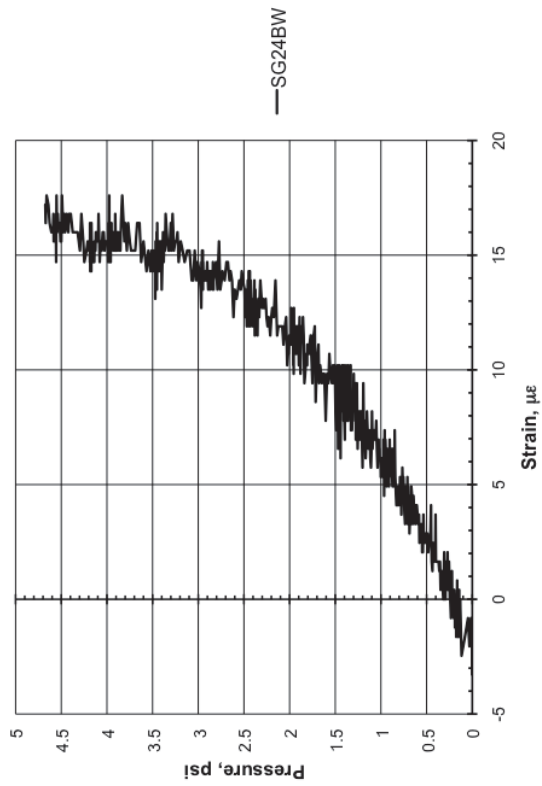


Figure A35. Checkout test 1, strain gage SG24BW.

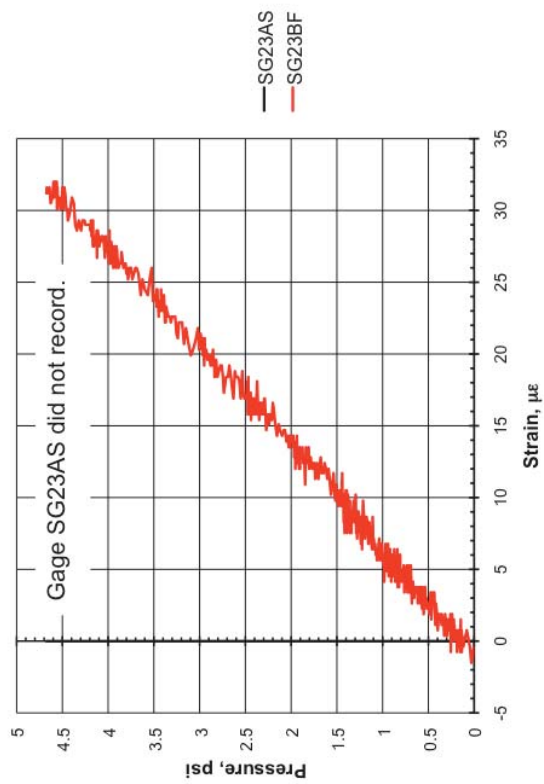


Figure A34. Checkout test 1, strain gages SG23AS and SG23BF.

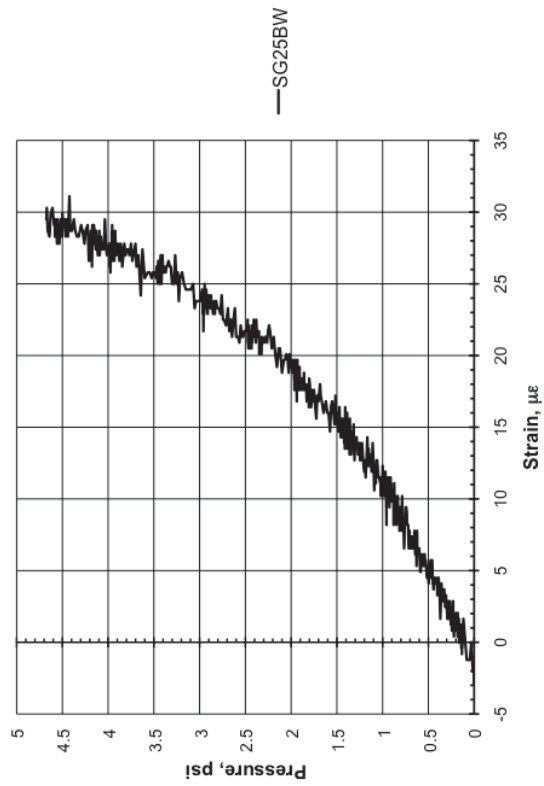


Figure A36. Checkout test 1, strain gage SG25BW.

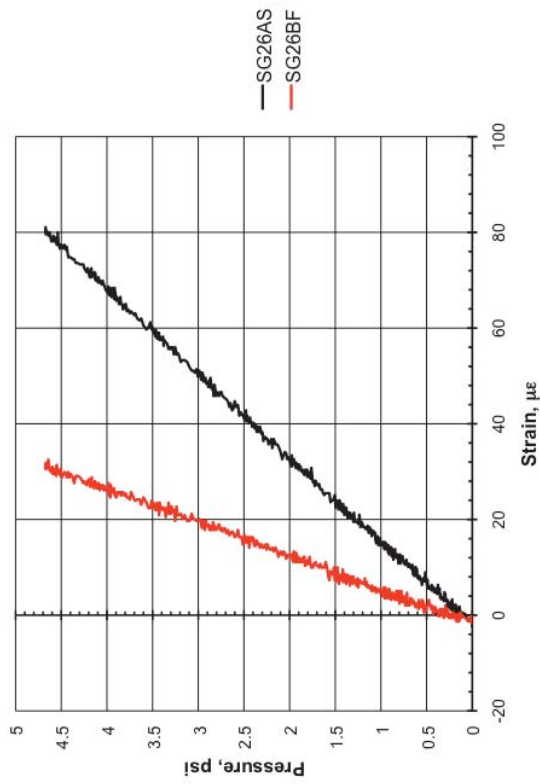


Figure A37. Checkout test 1, strain gages SG26AS and SG26BF.

A11

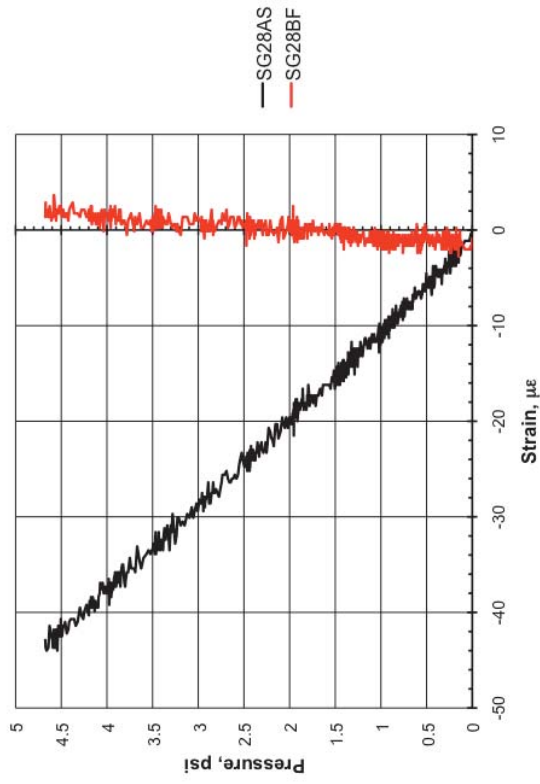


Figure A39. Checkout test 1, strain gages SG28AS and SG28BF.

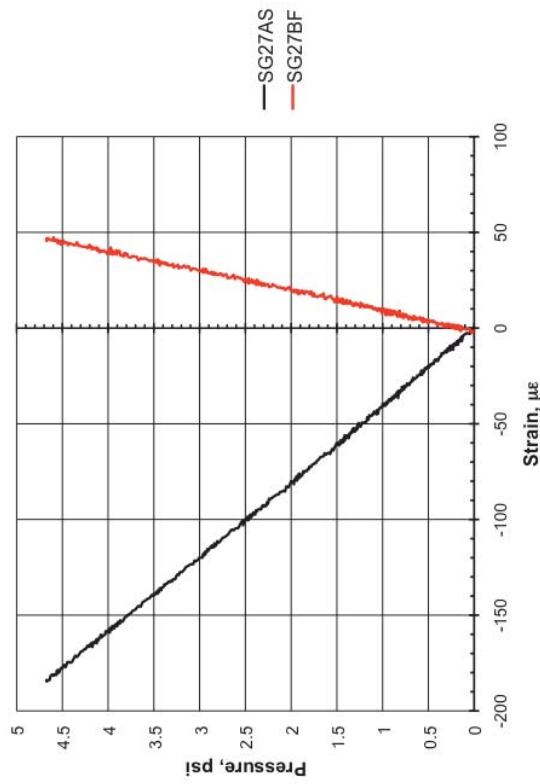


Figure A38. Checkout test 1, strain gages SG27AS and SG27BF.

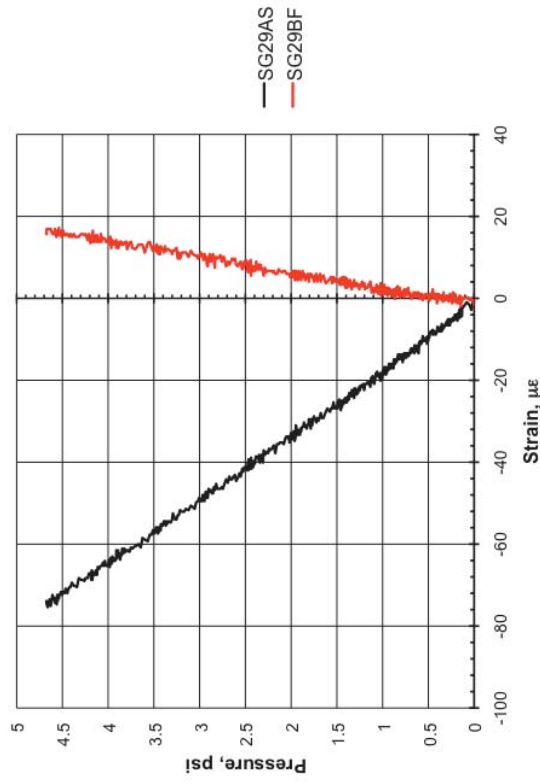


Figure A40. Checkout test 1, strain gages SG29AS and SG29BF.

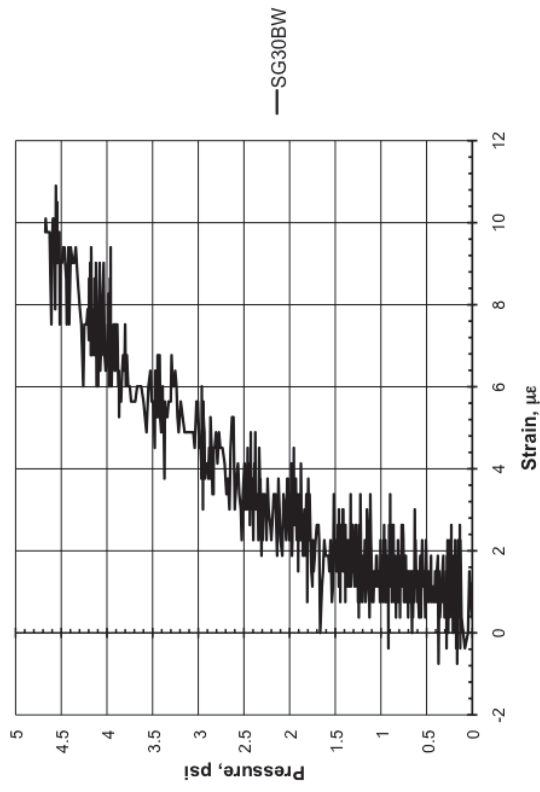


Figure A41. Checkout test 1, strain gage SG30BW.

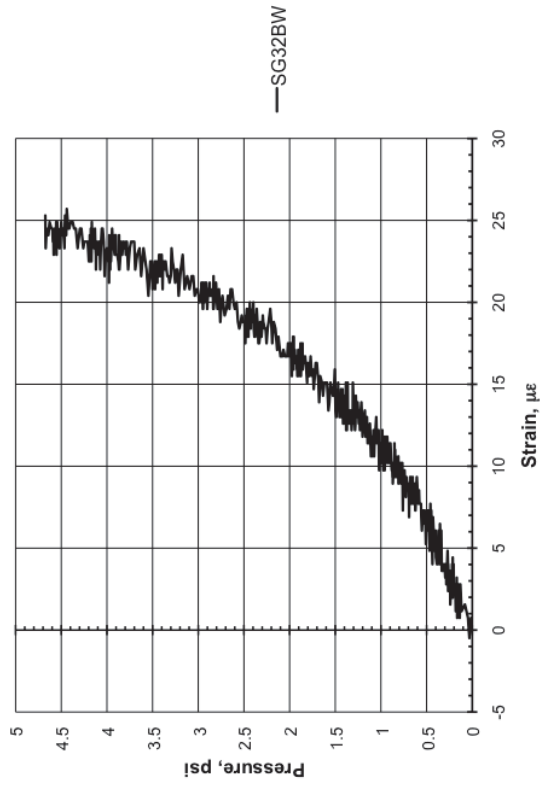


Figure A43. Checkout test 1, strain gage SG32BW.

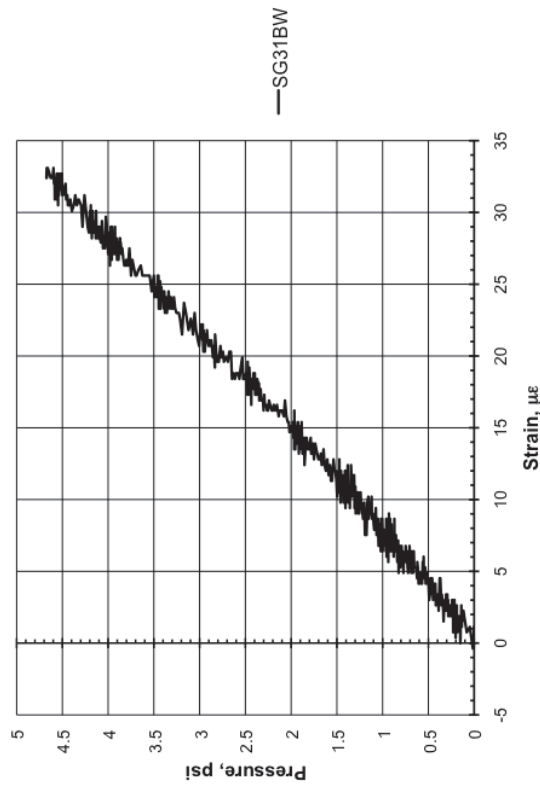


Figure A42. Checkout test 1, strain gage SG31BW.

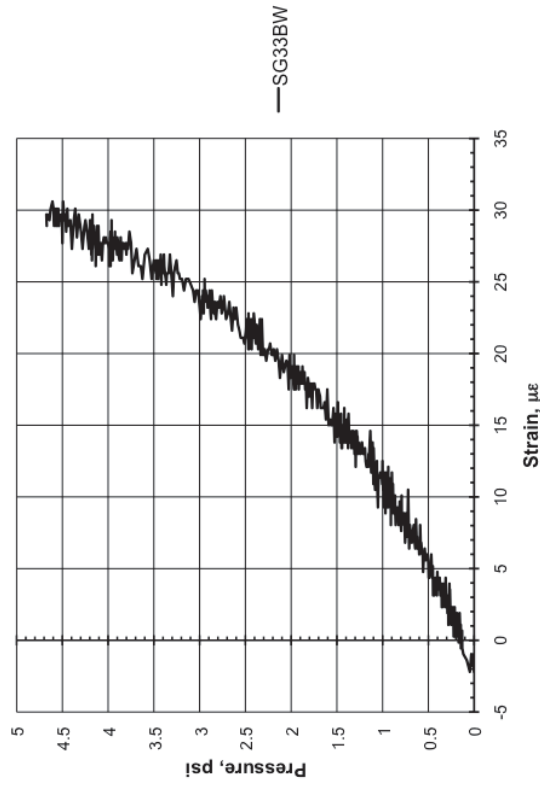


Figure A44. Checkout test 1, strain gage SG33BW.



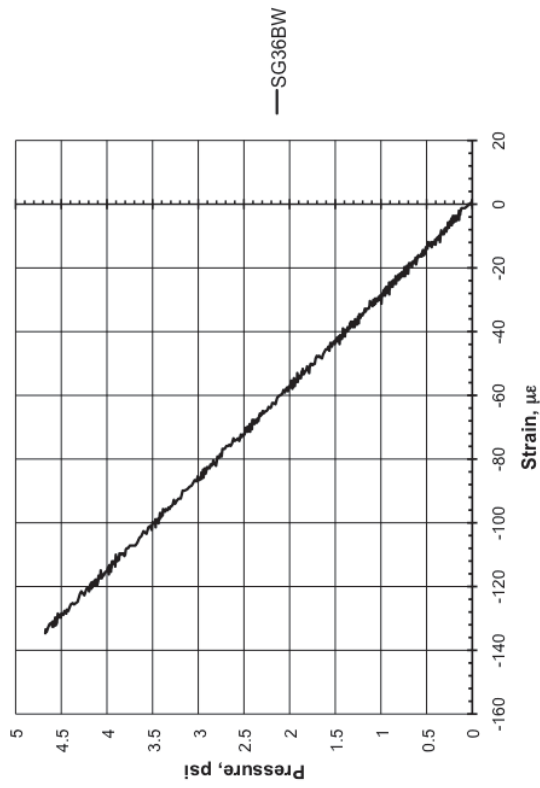


Figure A47. Checkout test 1, strain gage SG36BW.

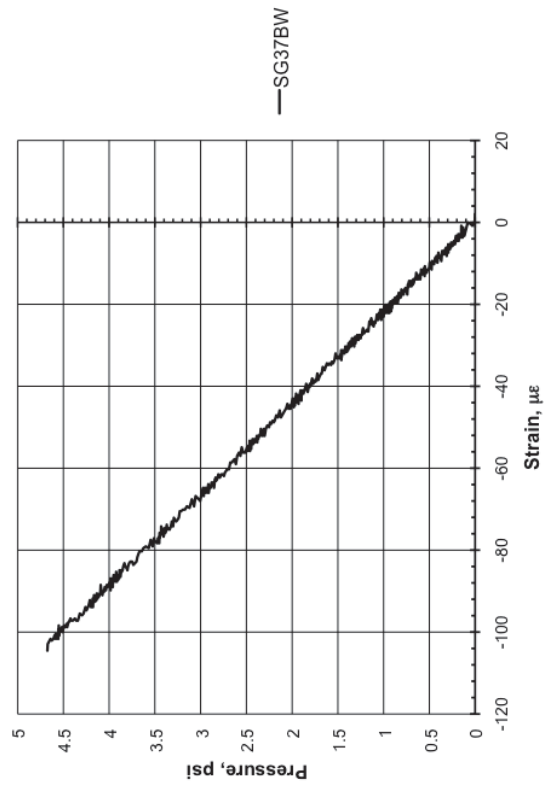


Figure A48. Checkout test 1, strain gage SG37BW.

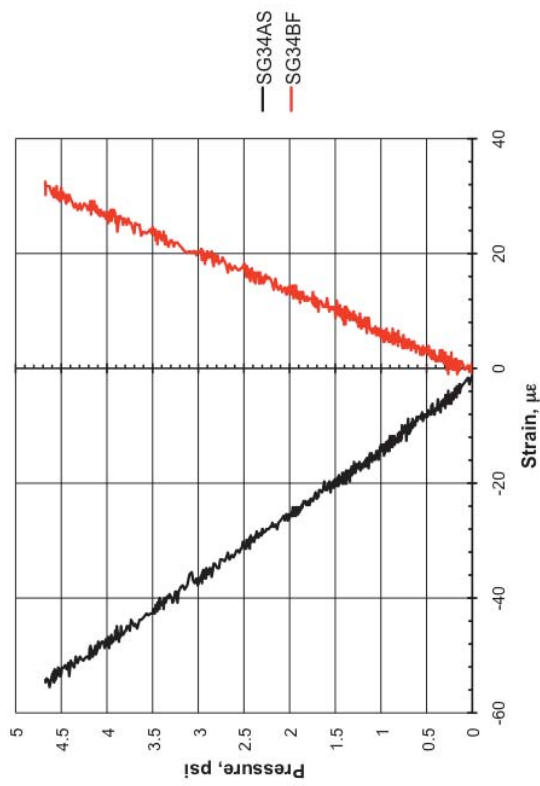


Figure A45. Checkout test 1, strain gages SG34AS and SG34BF.

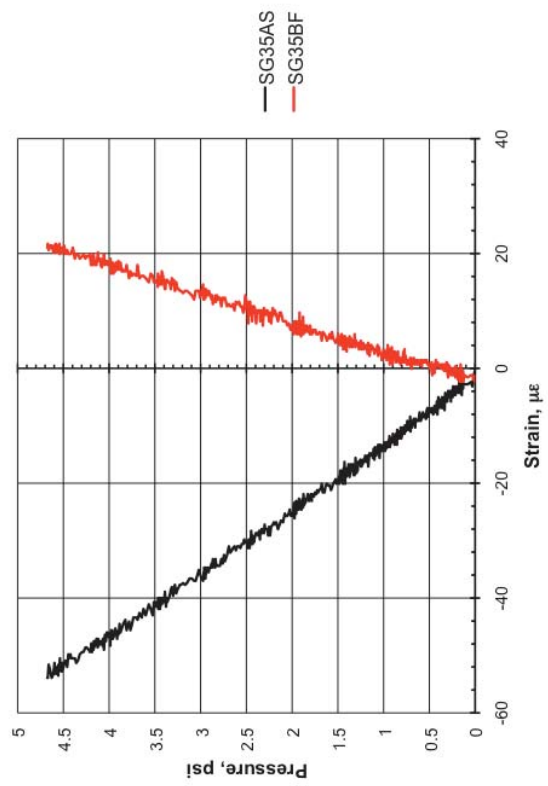


Figure A46. Checkout test 1, strain gages SG35AS and SG35BF.

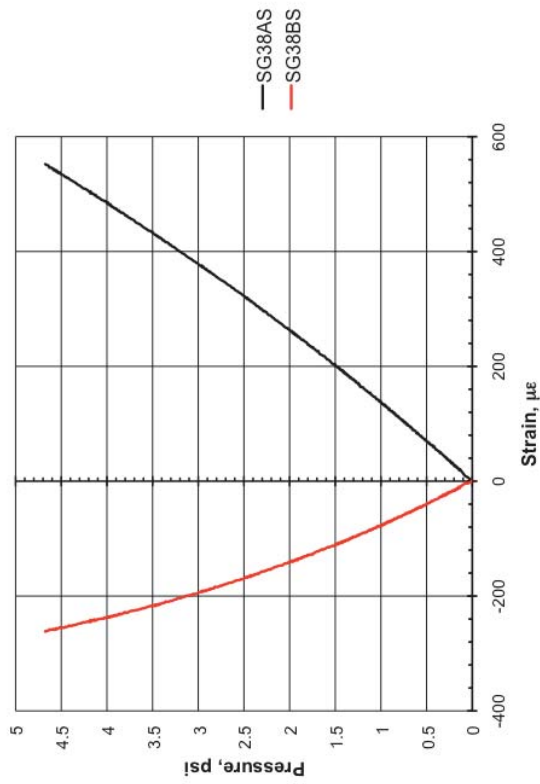


Figure A49. Checkout test 1, strain gages SG38AS and SG38BS.

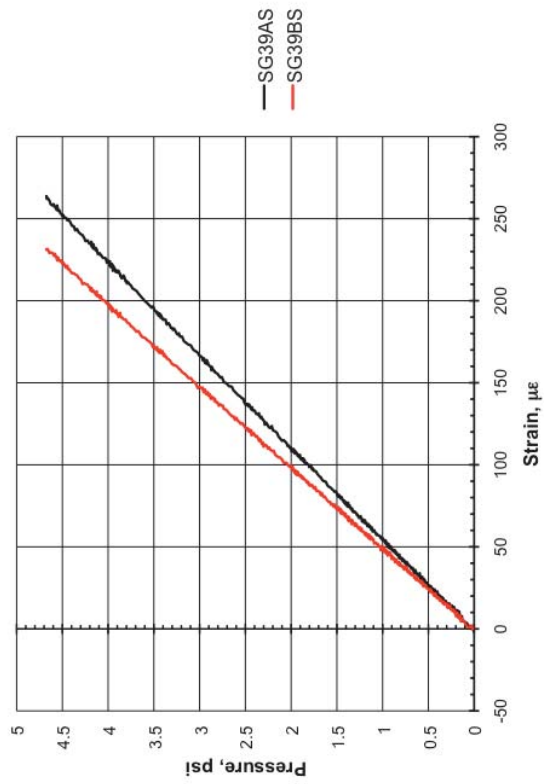


Figure A50. Checkout test 1, strain gages SG39AS and SG39BS.

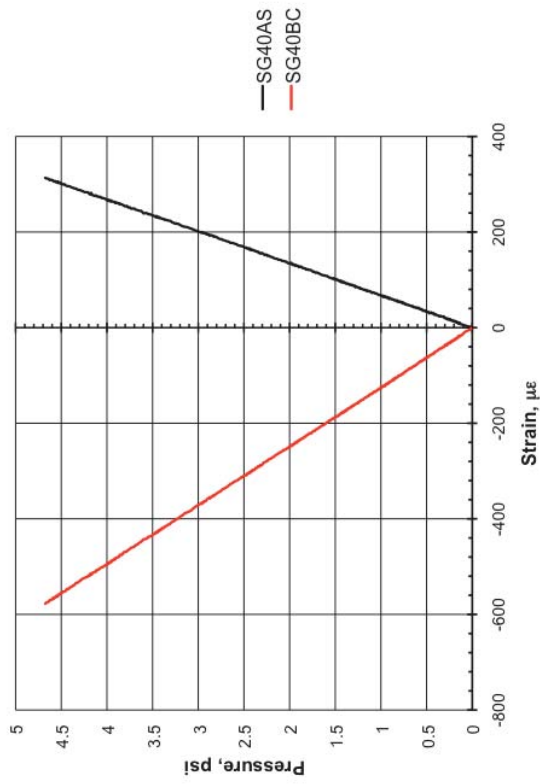


Figure A51. Checkout test 1, strain gages SG40AS and SG40BC.

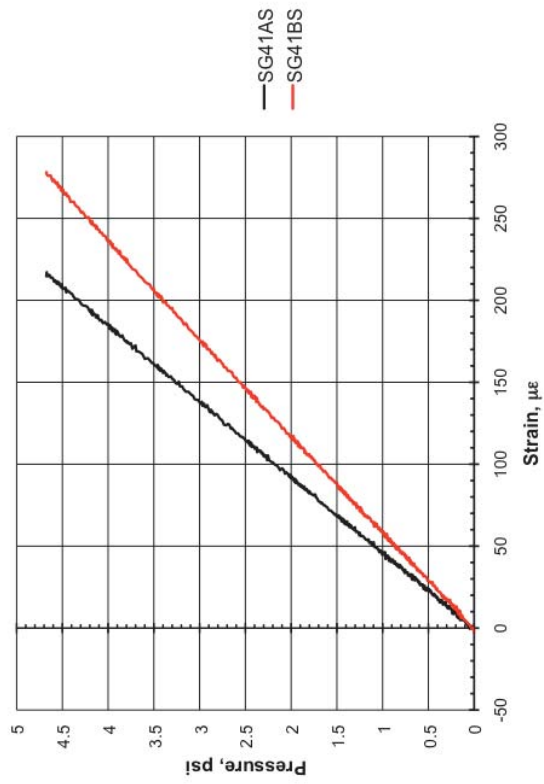


Figure A52. Checkout test 1, strain gages SG41AS and SG41BS.

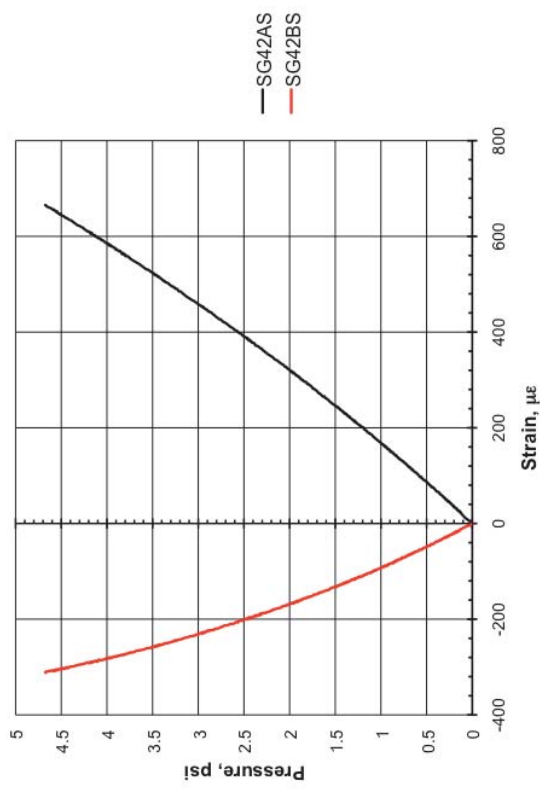


Figure A53. Checkout test 1, strain gages SG42AS and SG42BS.

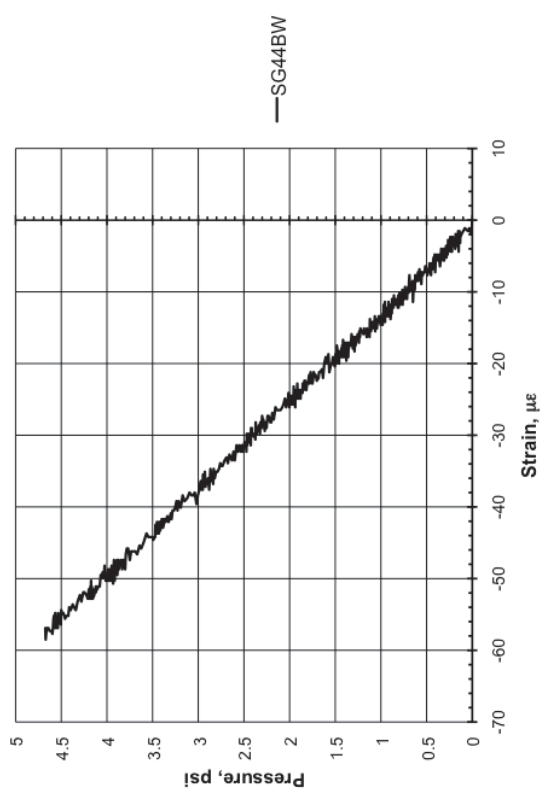


Figure A55. Checkout test 1, strain gage SG44BW.

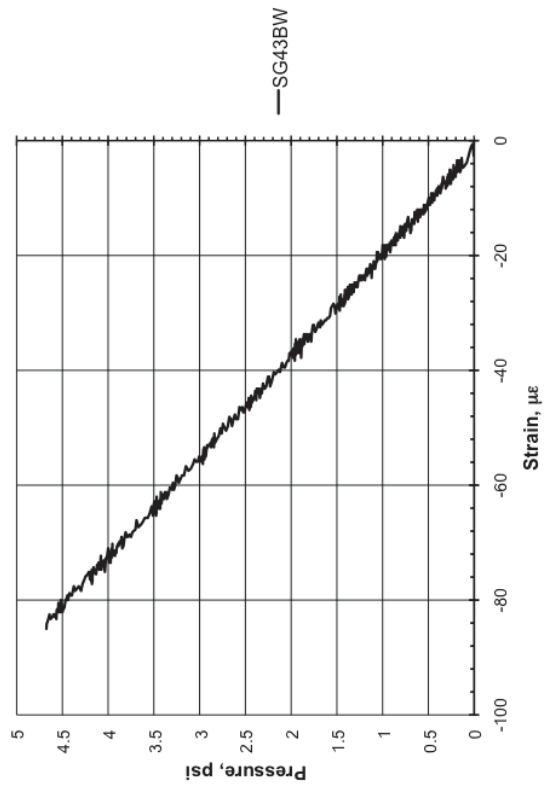


Figure A54. Checkout test 1, strain gage SG43BW.

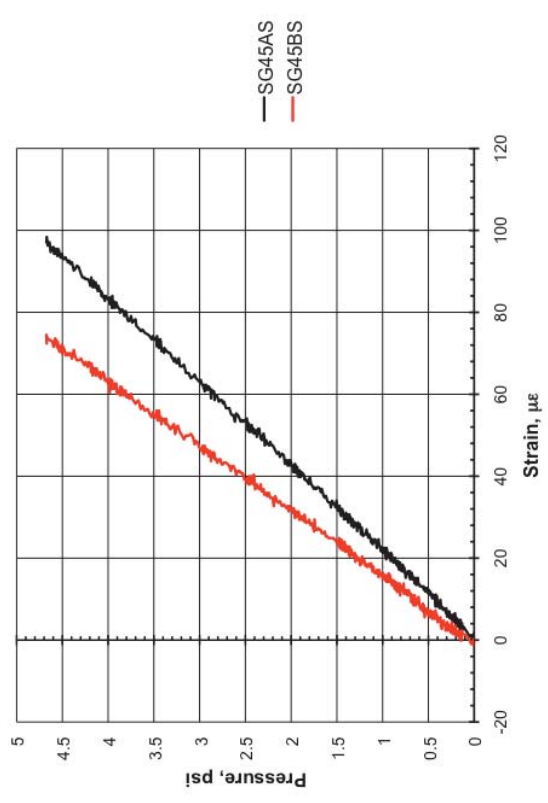


Figure A56. Checkout test 1, strain gages SG45AS and SG45BS.

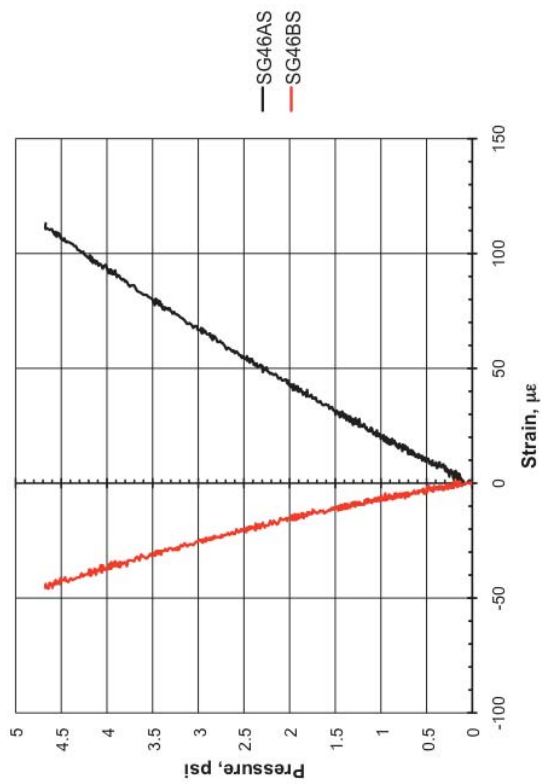


Figure A57. Checkout test 1, strain gages SG46AS and SG46BS.

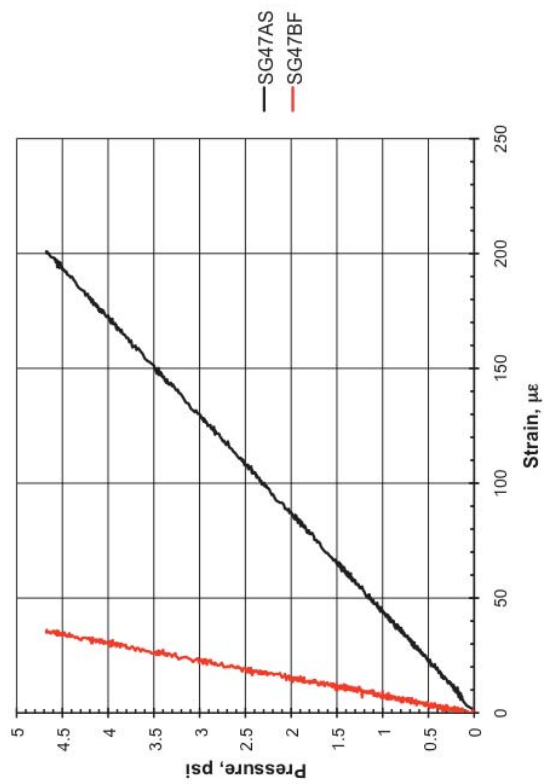


Figure A58. Checkout test 1, strain gages SG47AS and SG47BF.

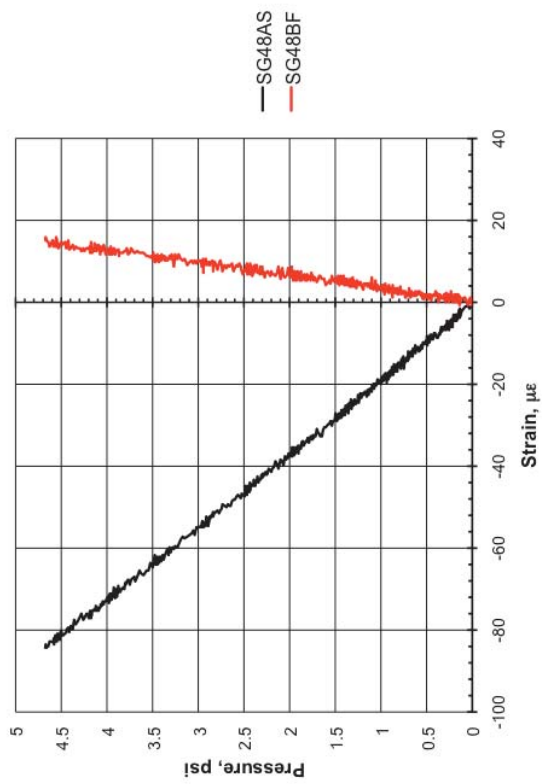


Figure A59. Checkout test 1, strain gages SG48AS and SG48BF.

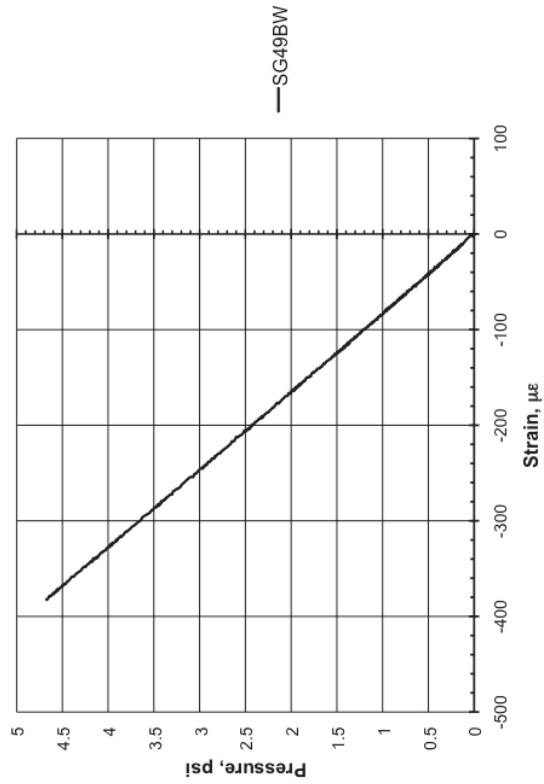


Figure A60. Checkout test 1, strain gage SG49BW.

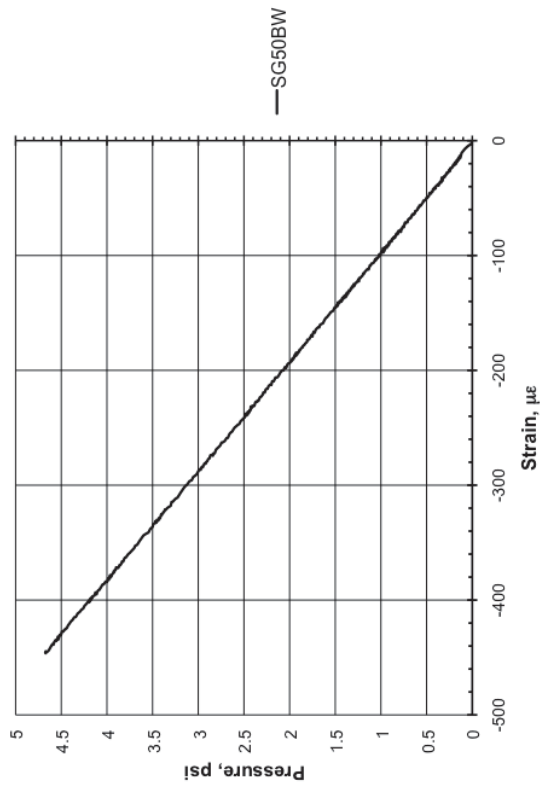


Figure A61. Checkout test 1, strain gage SG50BW.

A17

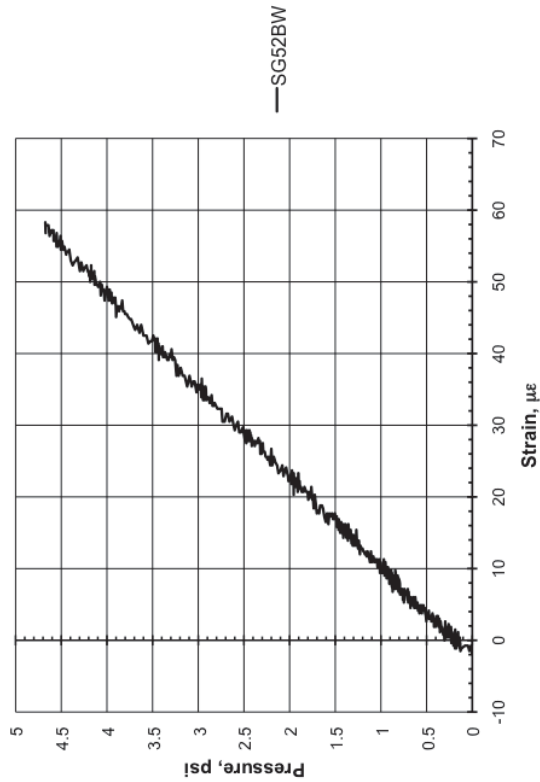


Figure A63. Checkout test 1, strain gage SG52BW.

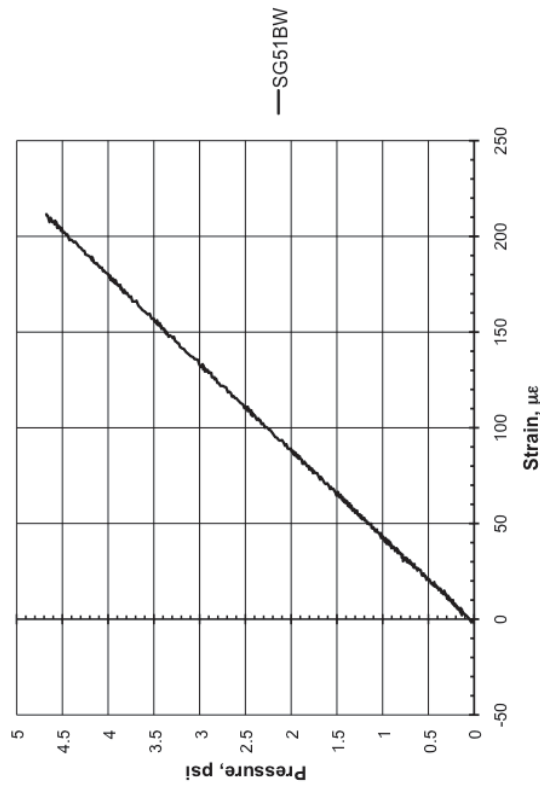


Figure A62. Checkout test 1, strain gage SG51BW.

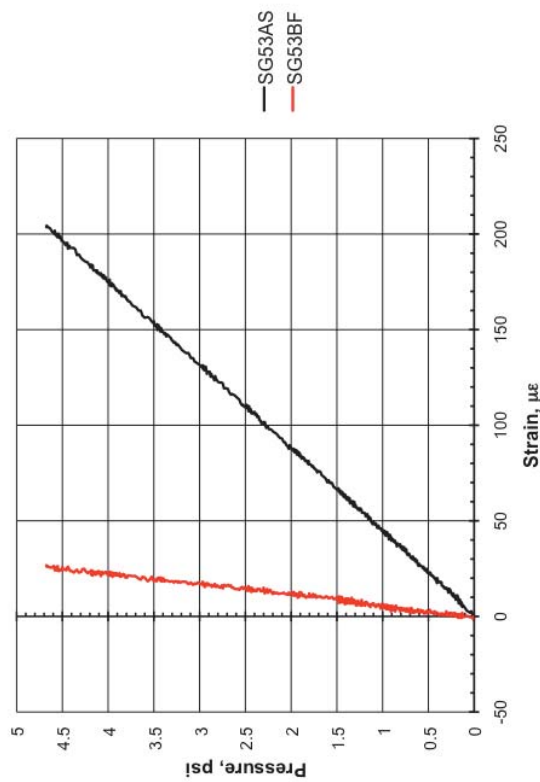


Figure A64. Checkout test 1, strain gages SG53AS and SG53BF.

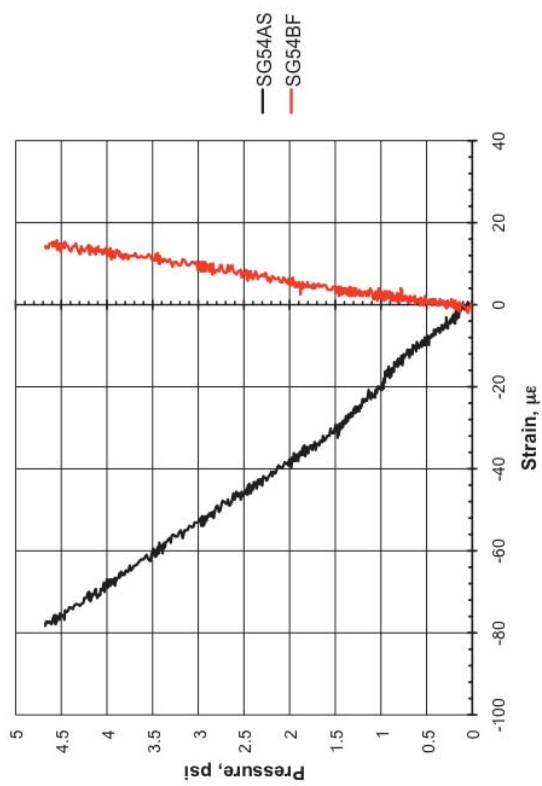


Figure A65. Checkout test 1, strain gages SG54AS and SG54BF.

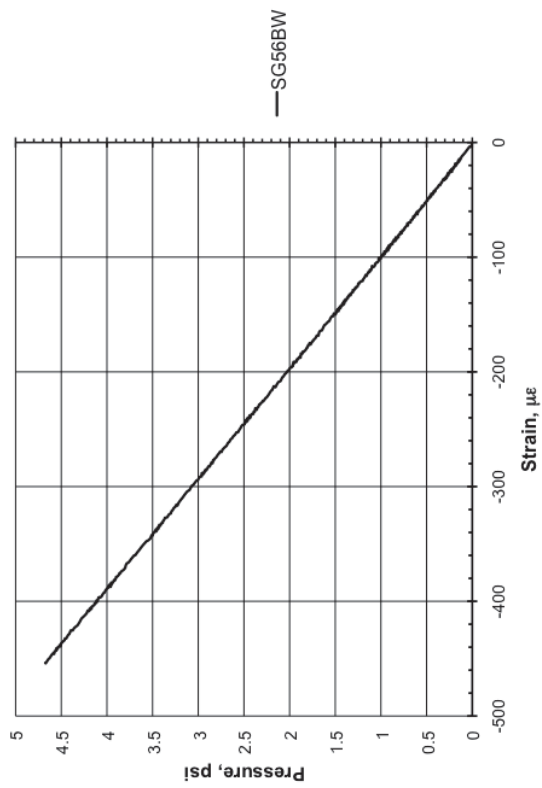


Figure A67. Checkout test 1, strain gage SG56BW.

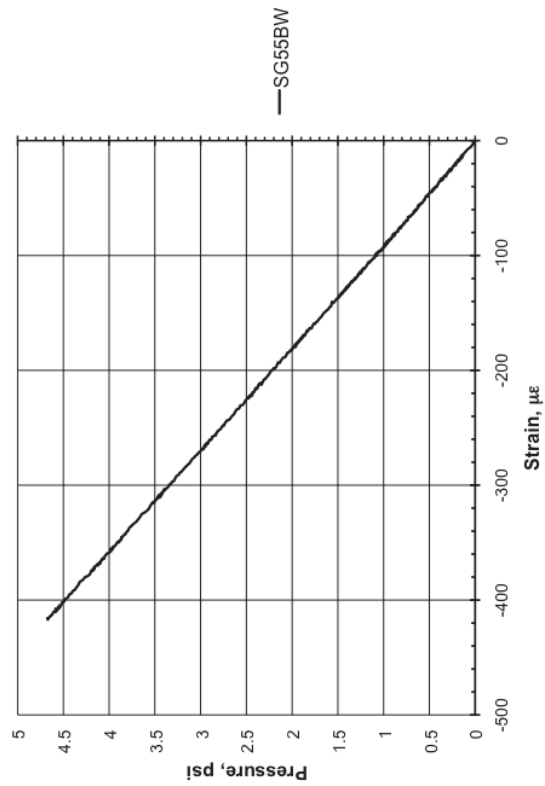


Figure A66. Checkout test 1, strain gage SG55BW.

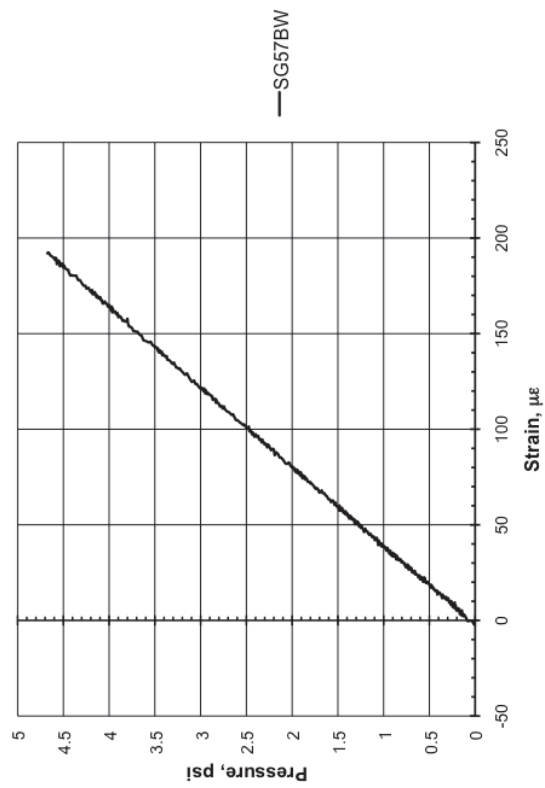


Figure A68. Checkout test 1, strain gage SG57BW.

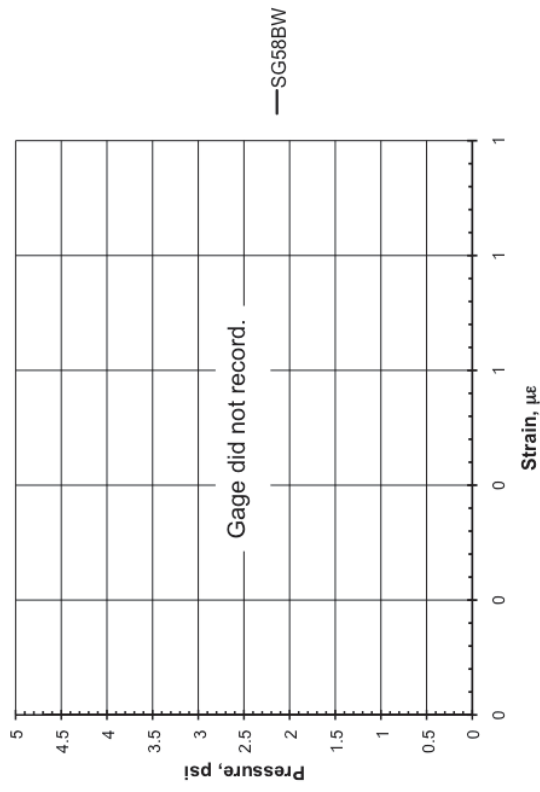


Figure A69. Checkout test 1, strain gage SG58BW.

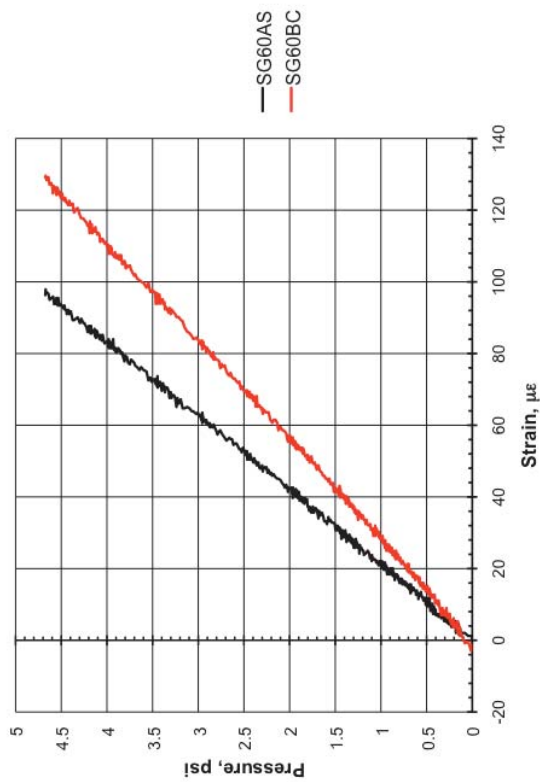


Figure A71. Checkout test 1, strain gages SG60AS and SG60BC.

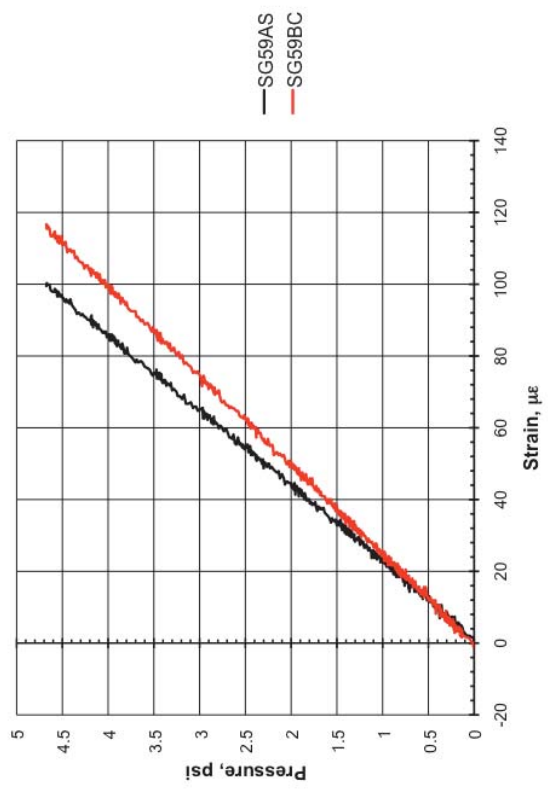


Figure A70. Checkout test 1, strain gages SG59AS and SG59BC.

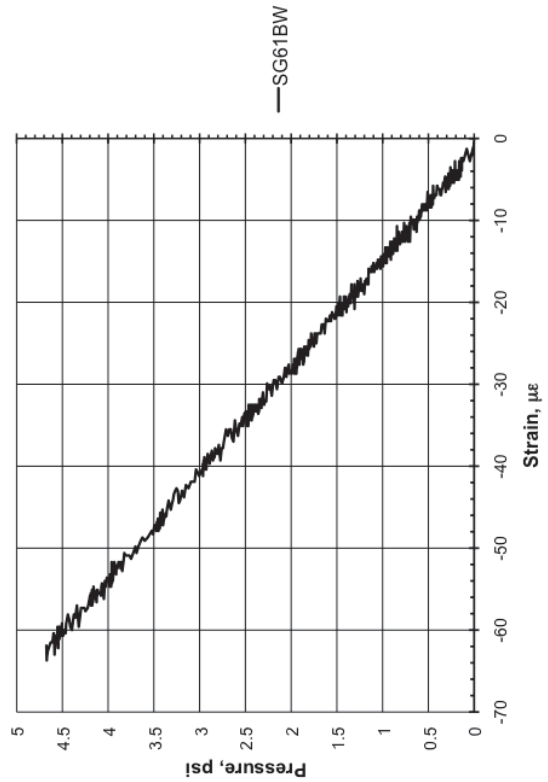


Figure A72. Checkout test 1, strain gage SG61BW.



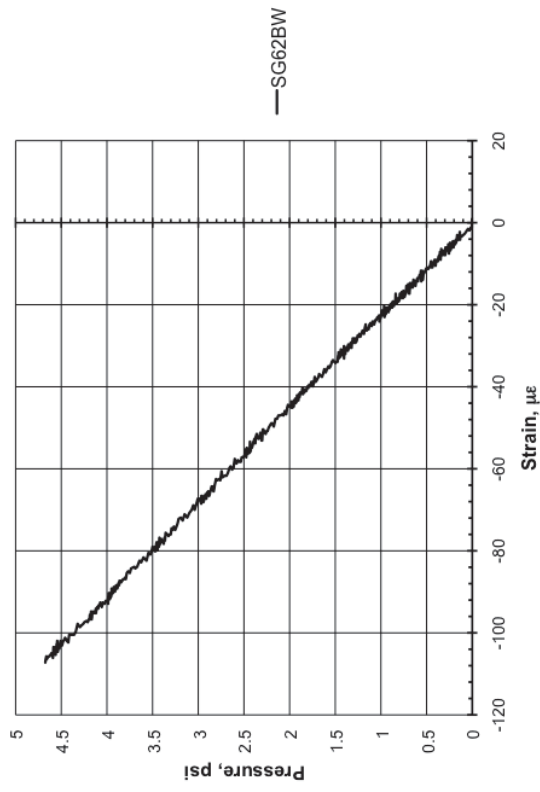


Figure A73. Checkout test 1, strain gage SG62BW.

A20

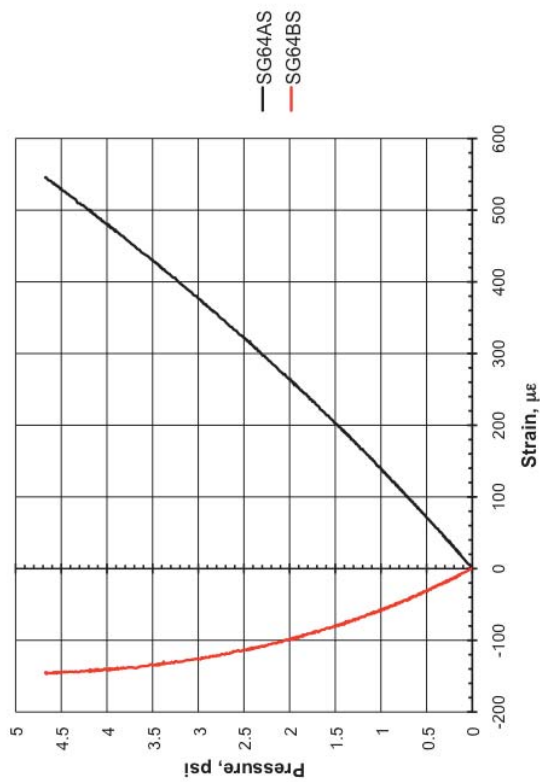


Figure A75. Checkout test 1, strain gages SG64AS and SG64BS.

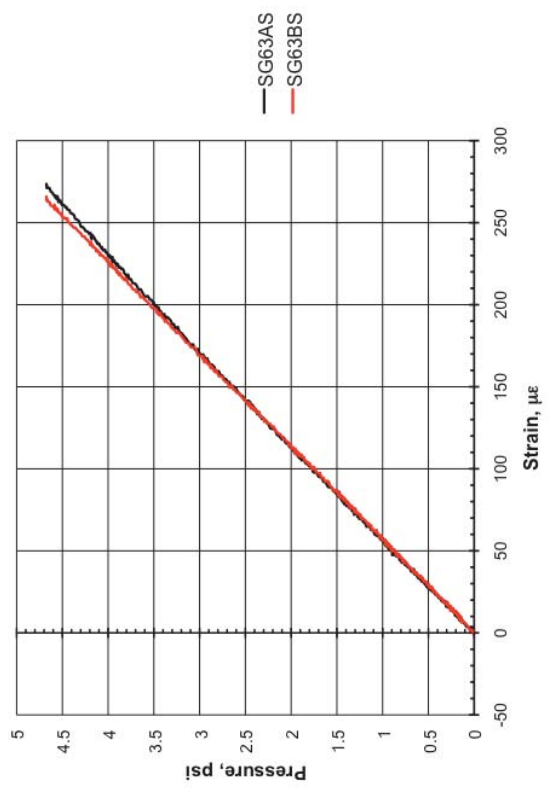


Figure A74. Checkout test 1, strain gages SG63AS and SG63BS.

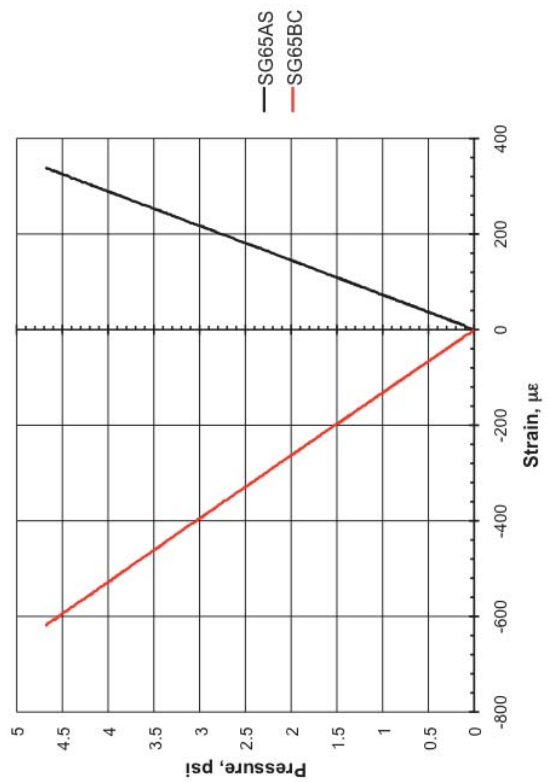


Figure A76. Checkout test 1, strain gages SG65AS and SG65BC.

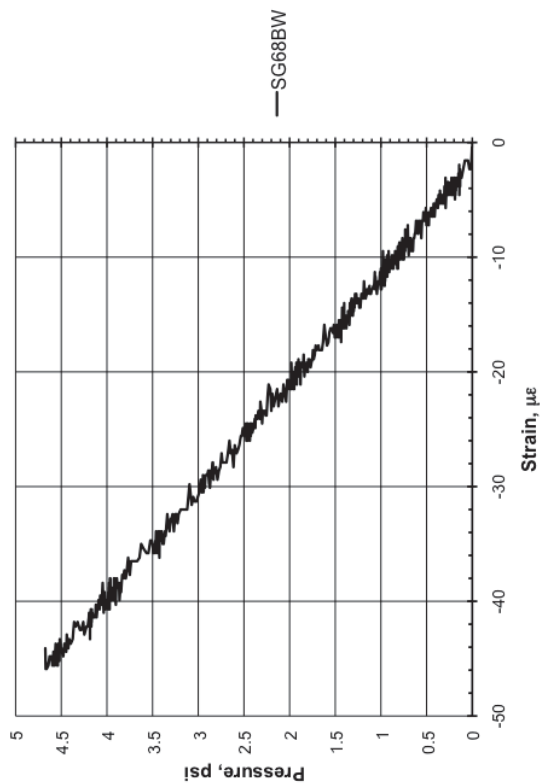


Figure A79. Checkout test 1, strain gage SG68BW.

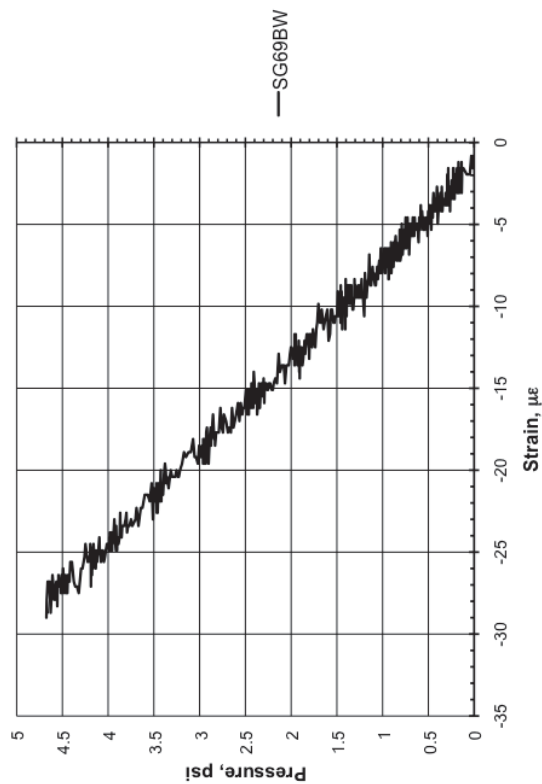


Figure A80. Checkout test 1, strain gage SG69BW.

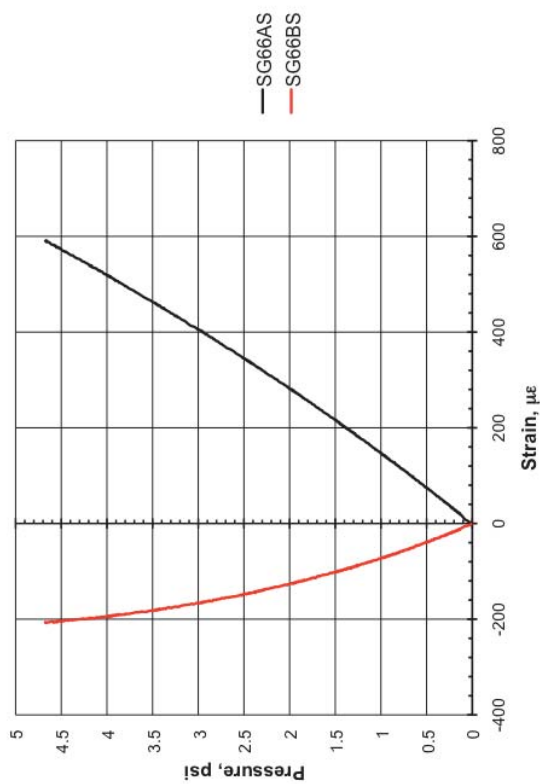


Figure A77. Checkout test 1, strain gages SG66AS and SG66BS.

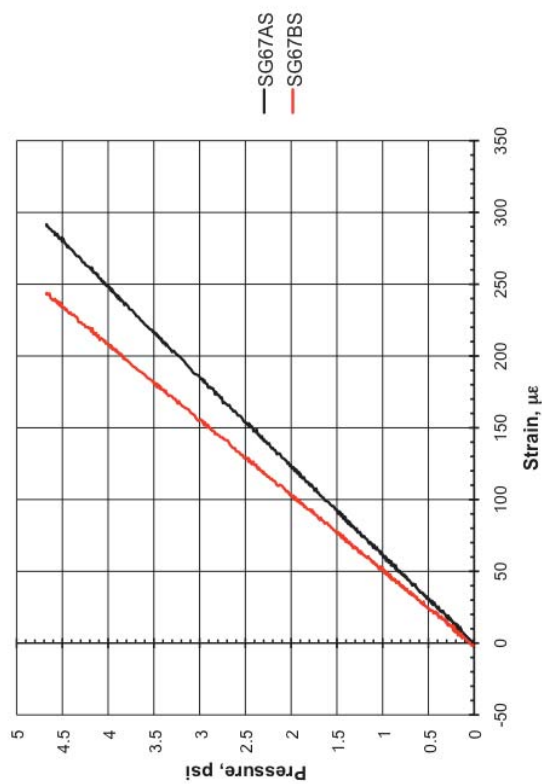


Figure A78. Checkout test 1, strain gages SG67AS and SG67BS.

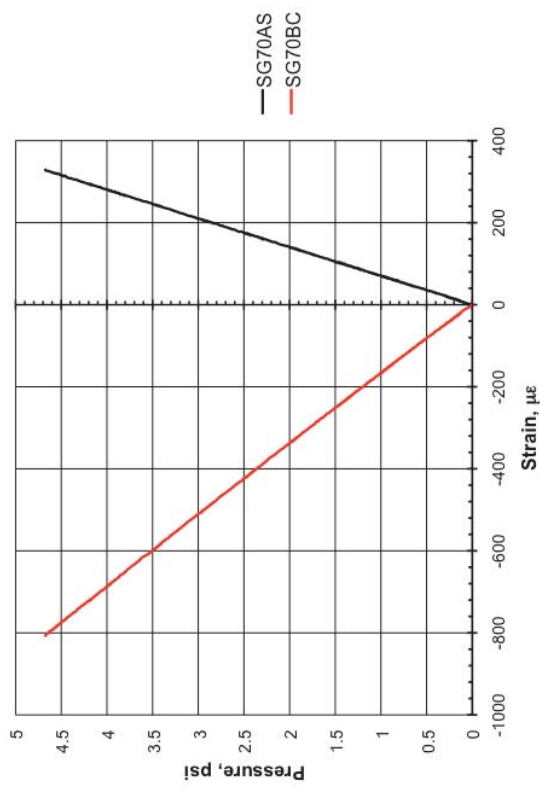


Figure A81. Checkout test 1, strain gages SG70AS and SG70BC.

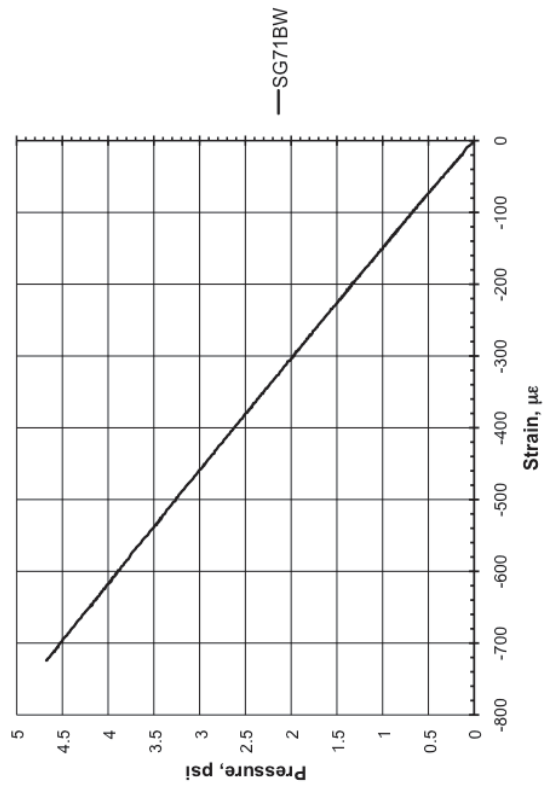


Figure A82. Checkout test 1, strain gage SG71BW.

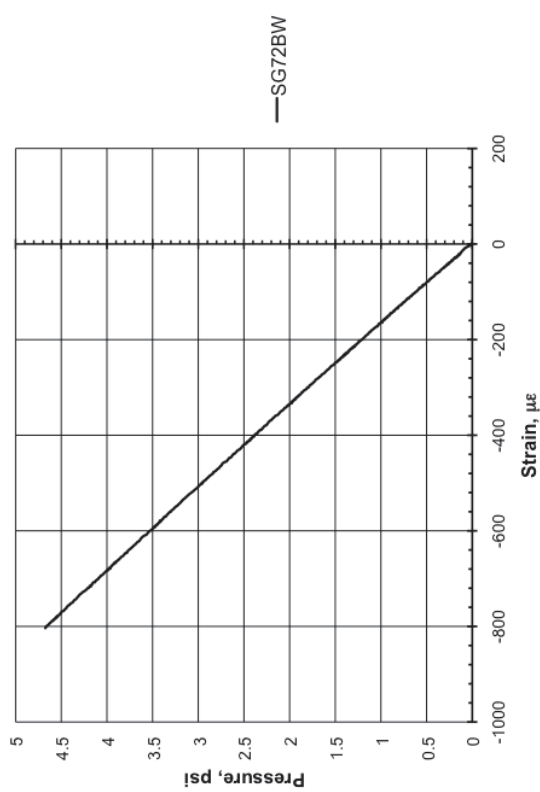


Figure A83. Checkout test 1, strain gage SG72BW.

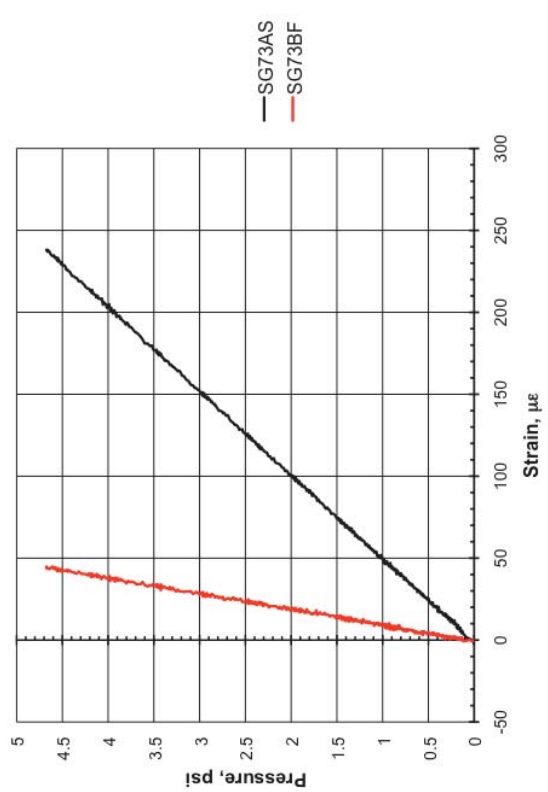


Figure A84. Checkout test 1, strain gages SG73AS and SG73BF.

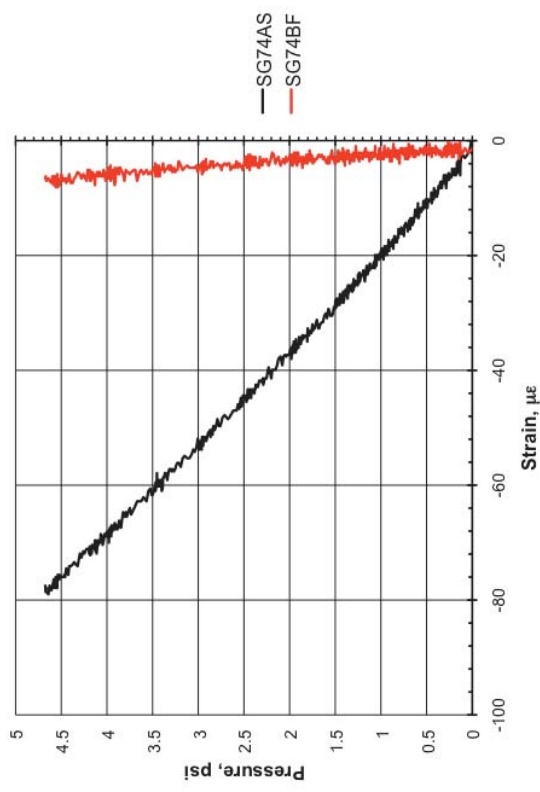


Figure A85. Checkout test 1, strain gages SG74AS and SG74BF.

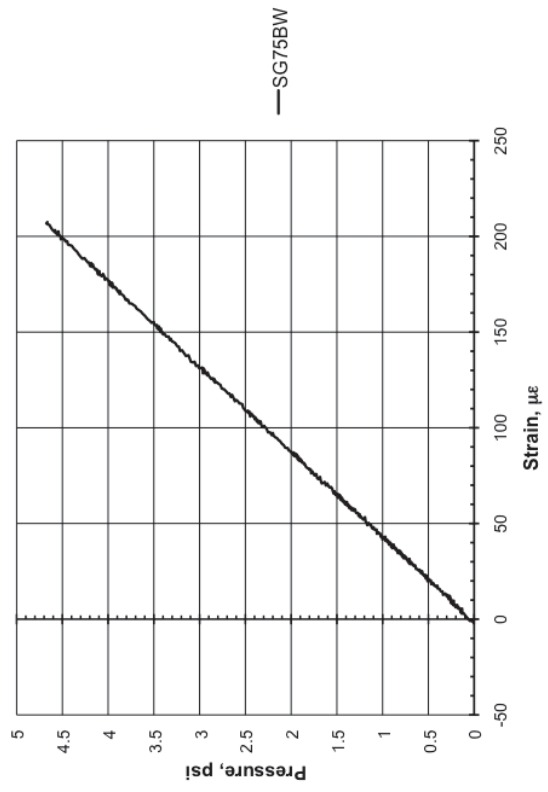


Figure A86. Checkout test 1, strain gage SG75BW.

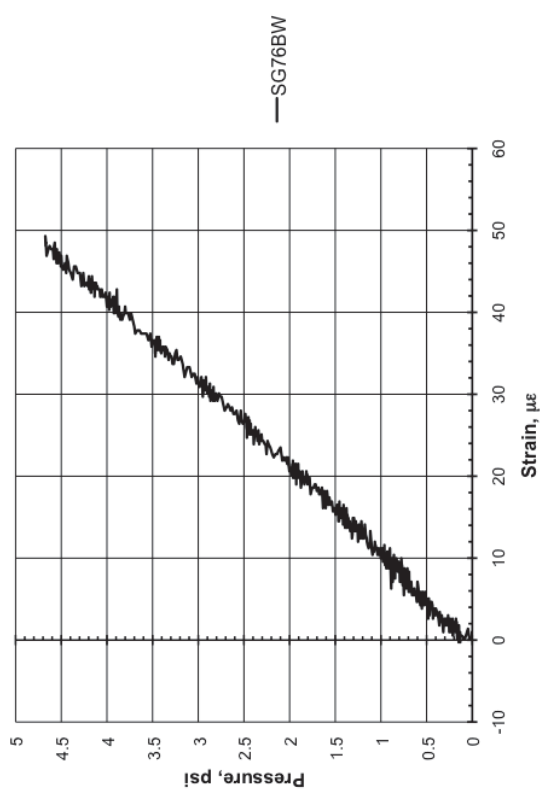


Figure A87. Checkout test 1, strain gage SG76BW.

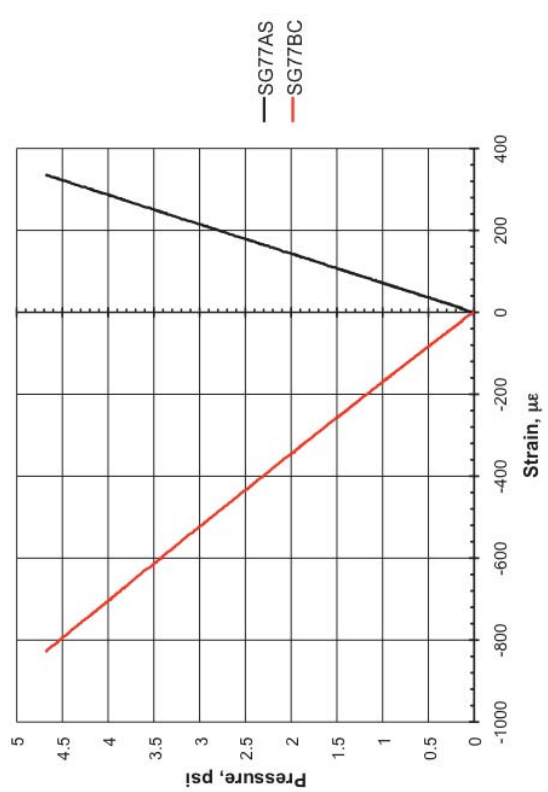


Figure A88. Checkout test 1, strain gages SG77AS and SG77BC.

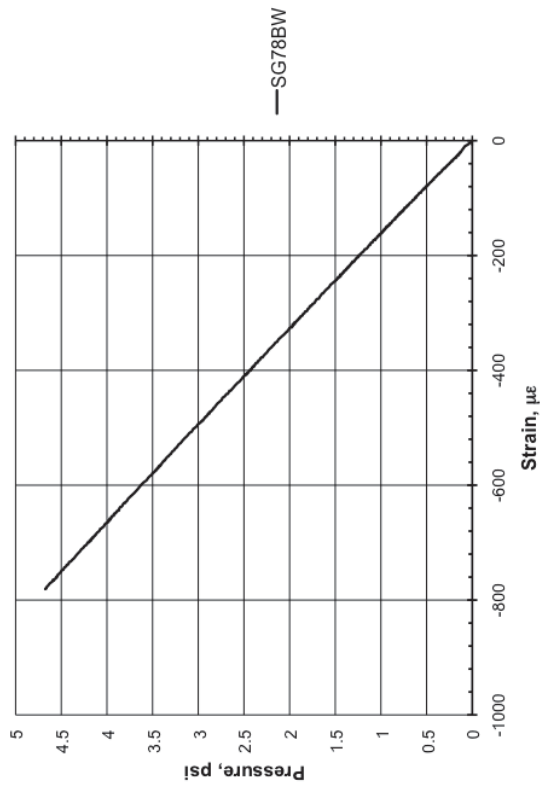


Figure A89. Checkout test 1, strain gage SG78BW.

A24

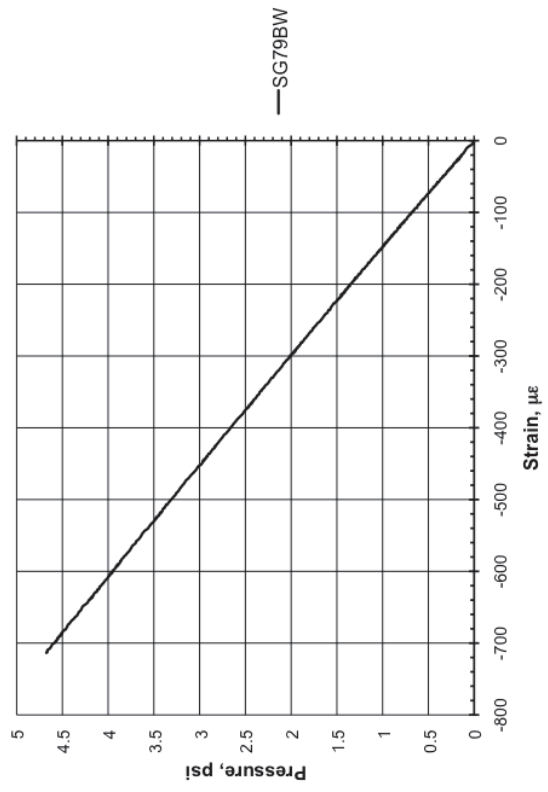


Figure A90. Checkout test 1, strain gage SG79BW.

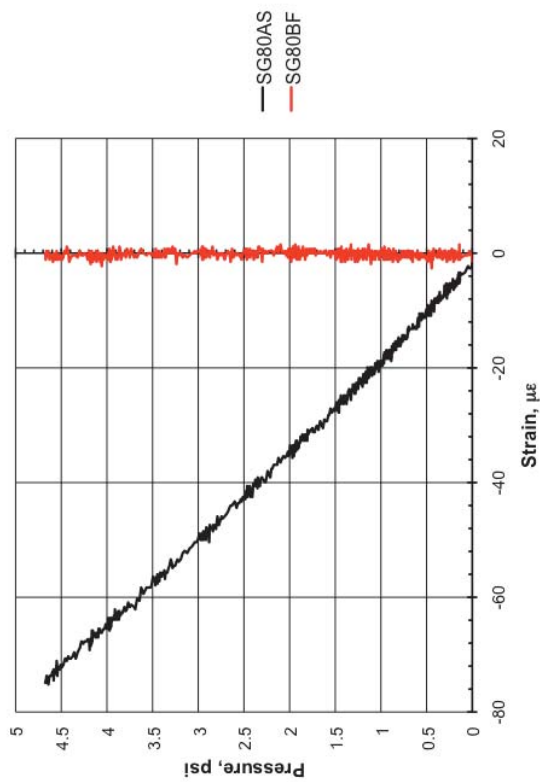


Figure A91. Checkout test 1, strain gages SG80AS and SG80BF.

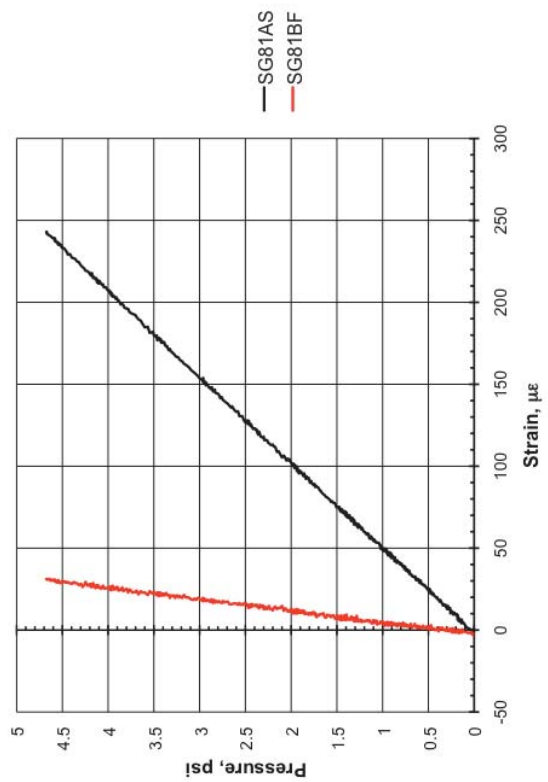


Figure A92. Checkout test 1, strain gages SG81AS and SG81BF.

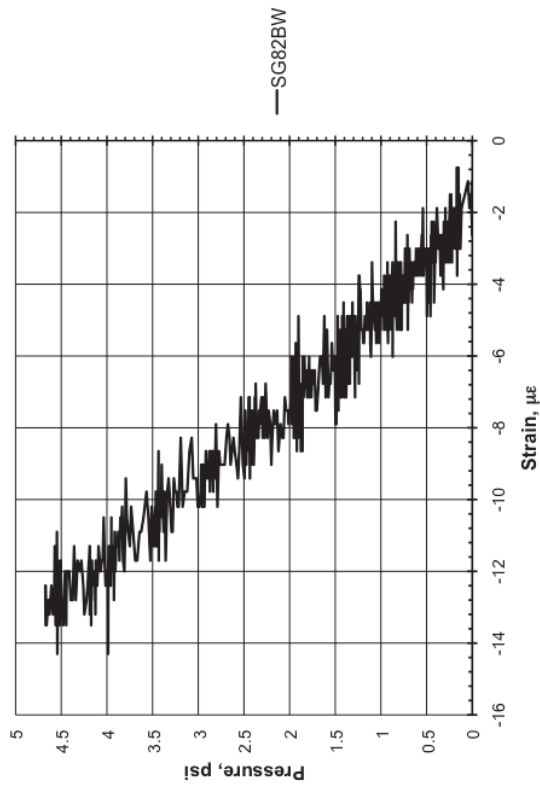


Figure A93. Checkout test 1, strain gage SG82BW.

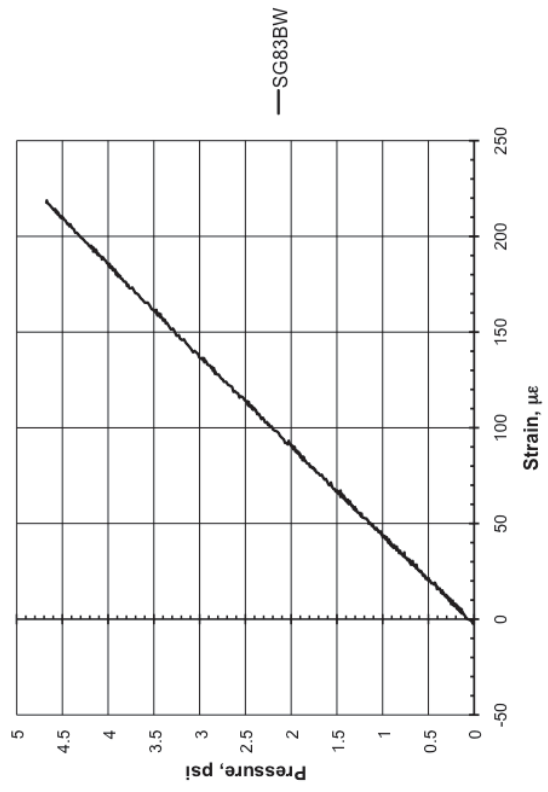


Figure A94. Checkout test 1, strain gage SG83BW.

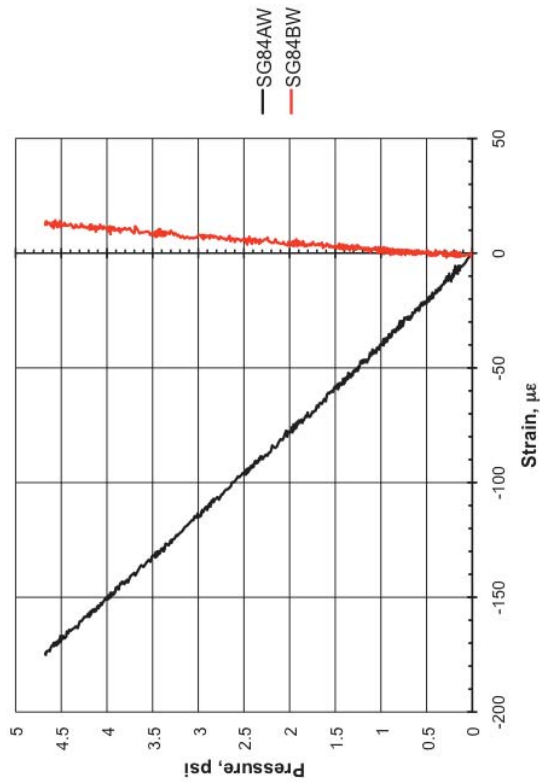


Figure A95. Checkout test 1, strain gages SG84AW and SG84BW.

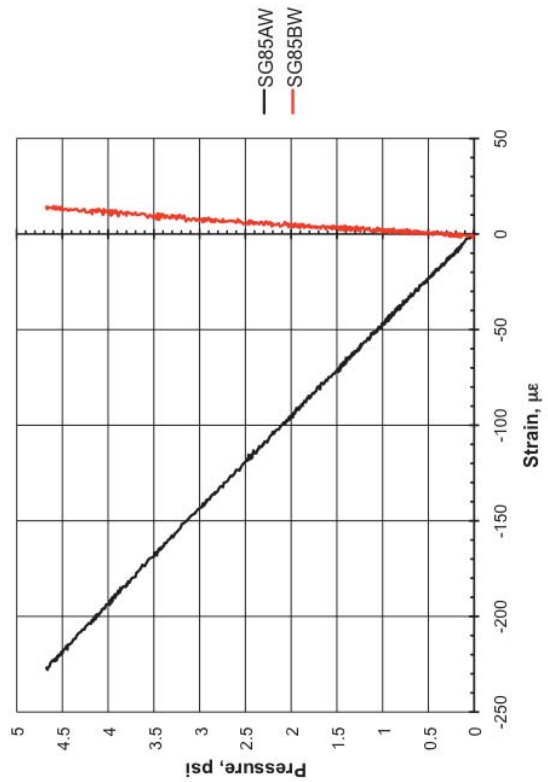


Figure A96. Checkout test 1, strain gages SG85AW and SG85BW.

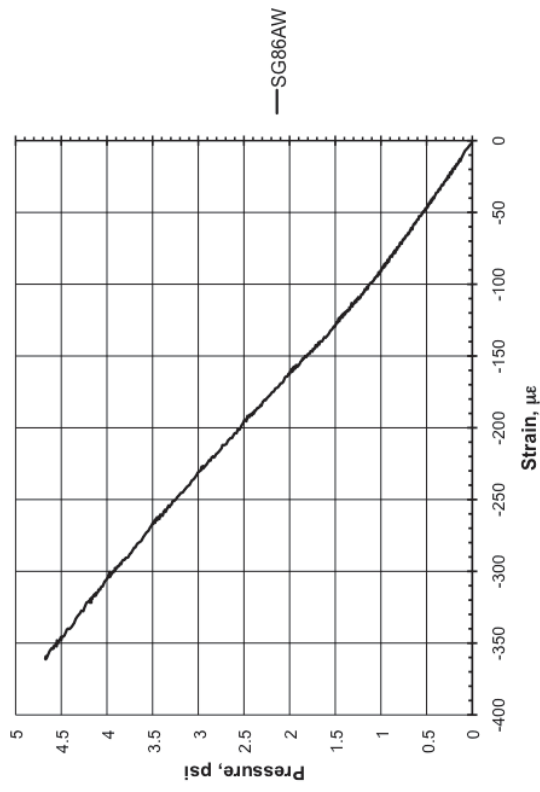


Figure A97. Checkout test 1, strain gage SG86AW.

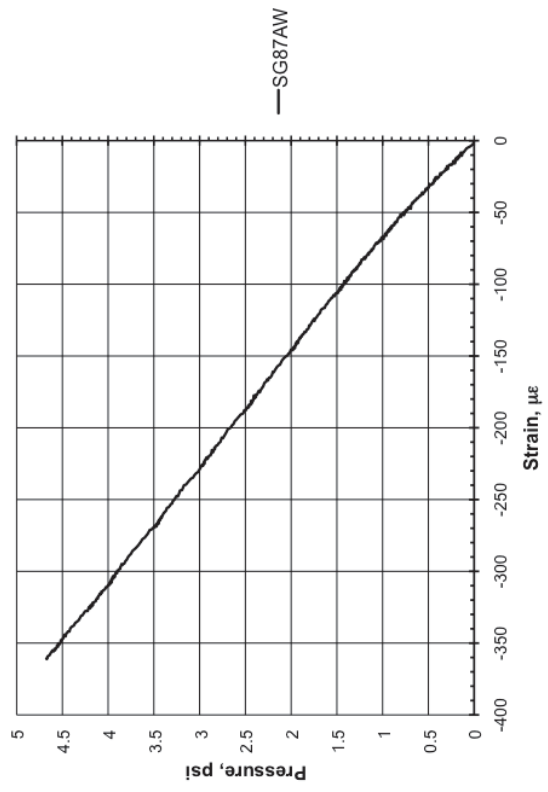


Figure A98. Checkout test 1, strain gage SG87AW.

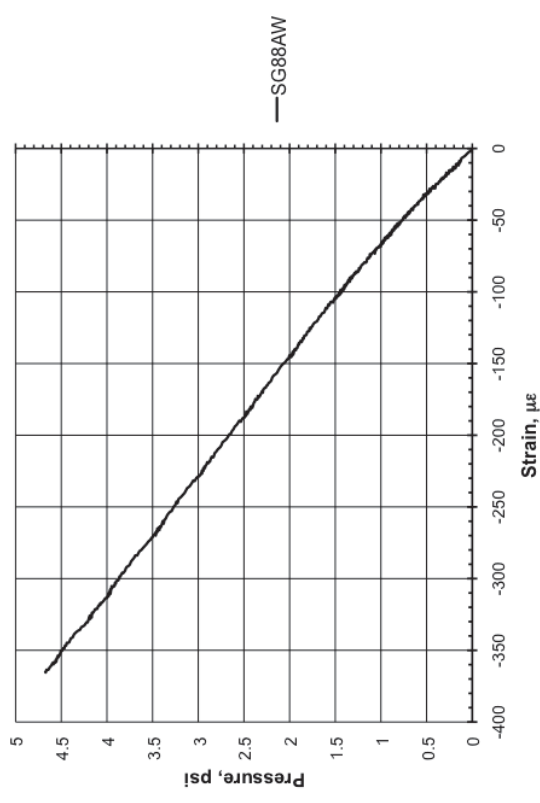


Figure A99. Checkout test 1, strain gage SG88AW.

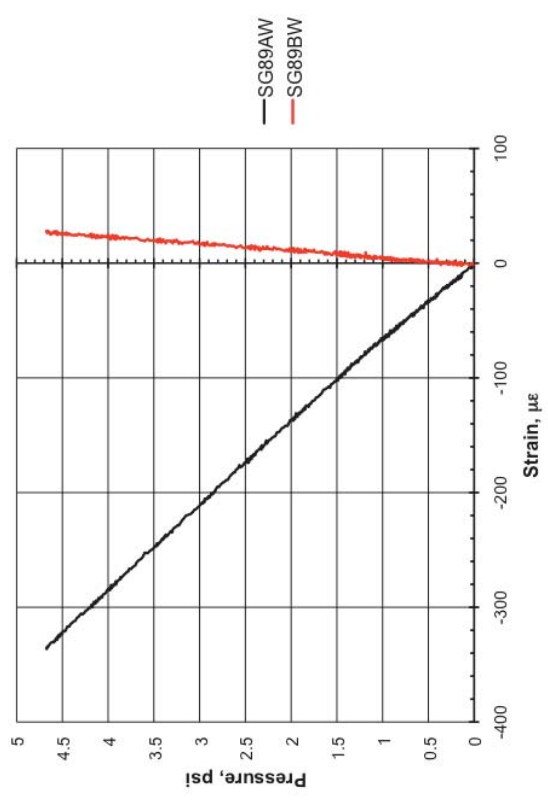


Figure A100. Checkout test 1, strain gages SG89AW and SG89BW.



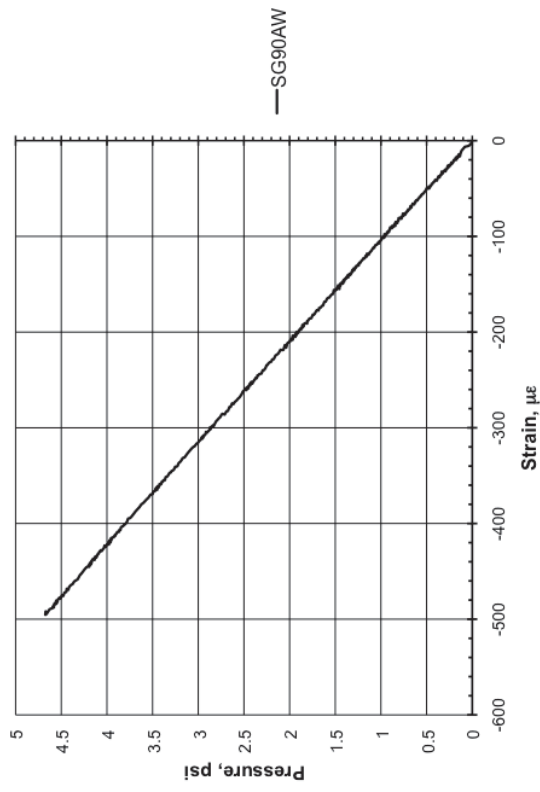


Figure A101. Checkout test 1, strain gage SG90AW.

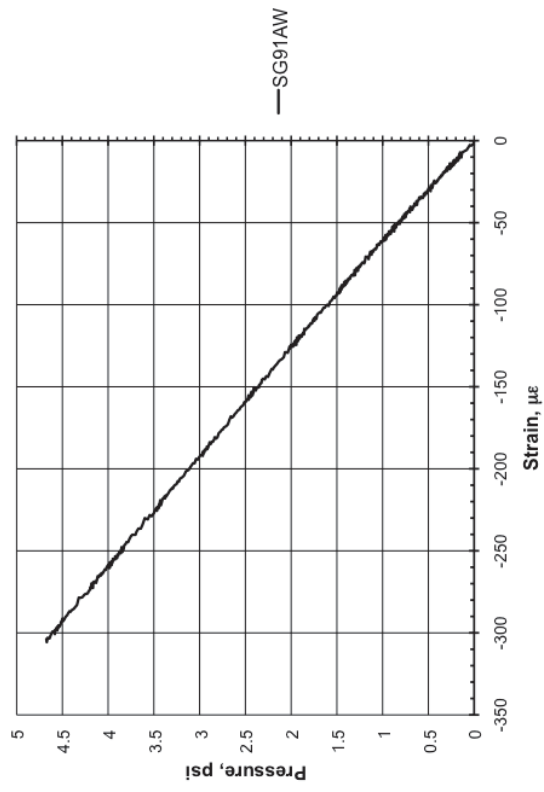


Figure A102. Checkout test 1, strain gage SG91AW.

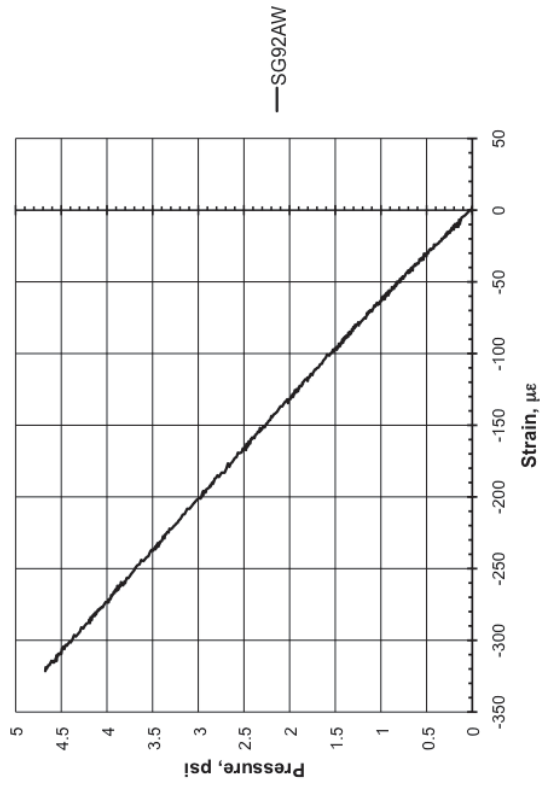


Figure A103. Checkout test 1, strain gage SG92AW.

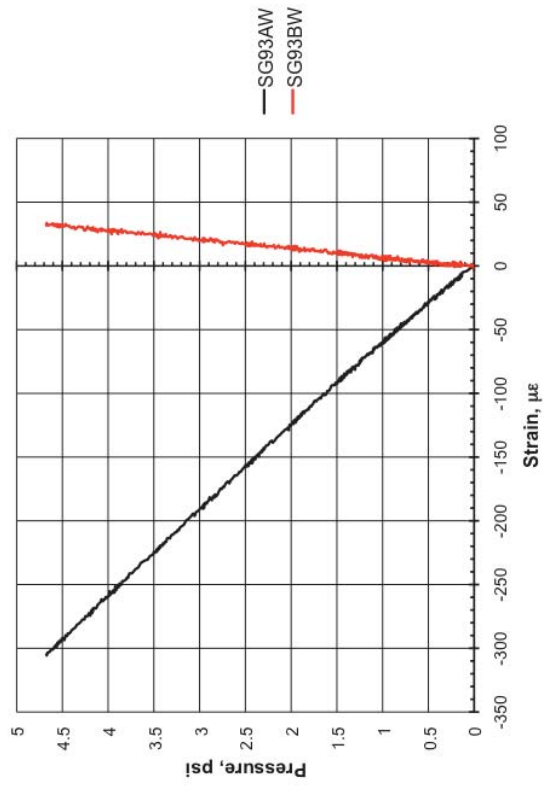


Figure A014. Checkout test 1, strain gages SG93AW and SG93BW.

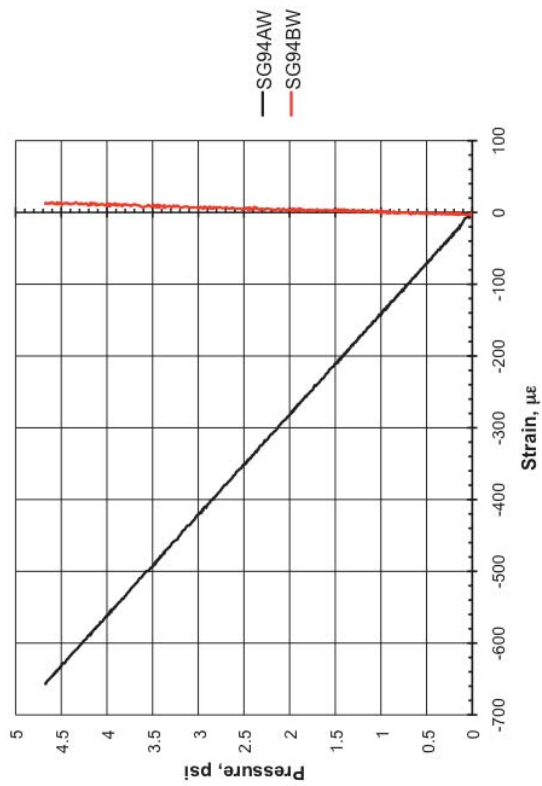


Figure A105. Checkout test 1, strain gages SG94AW and SG94BW.

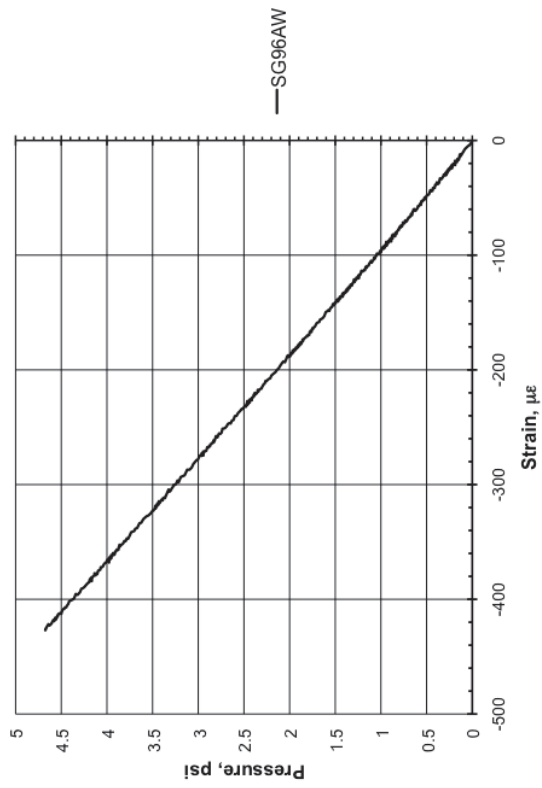


Figure A107. Checkout test 1, strain gage SG96AW.

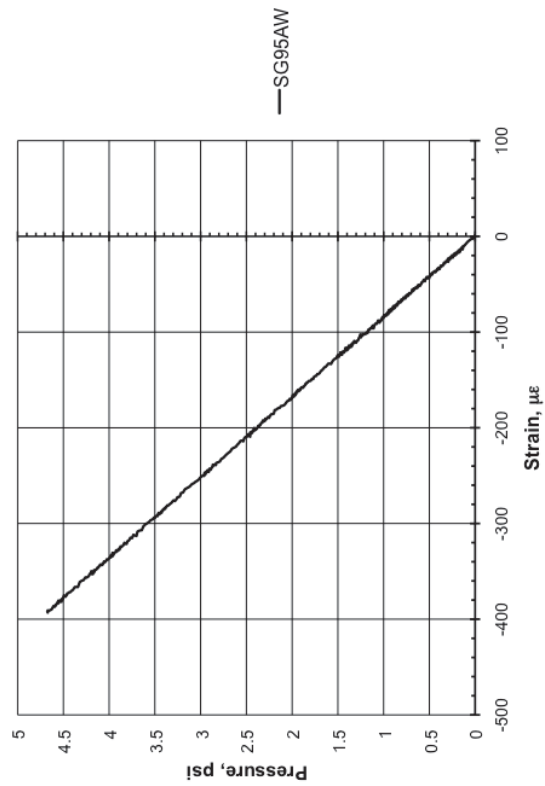


Figure A106. Checkout test 1, strain gage SG95AW.

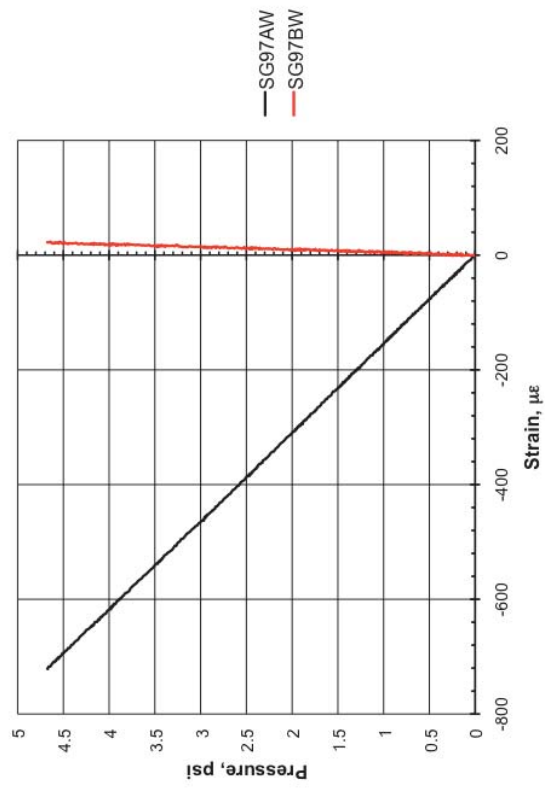


Figure A108. Checkout test 1, strain gages SG97AW and SG97BW.

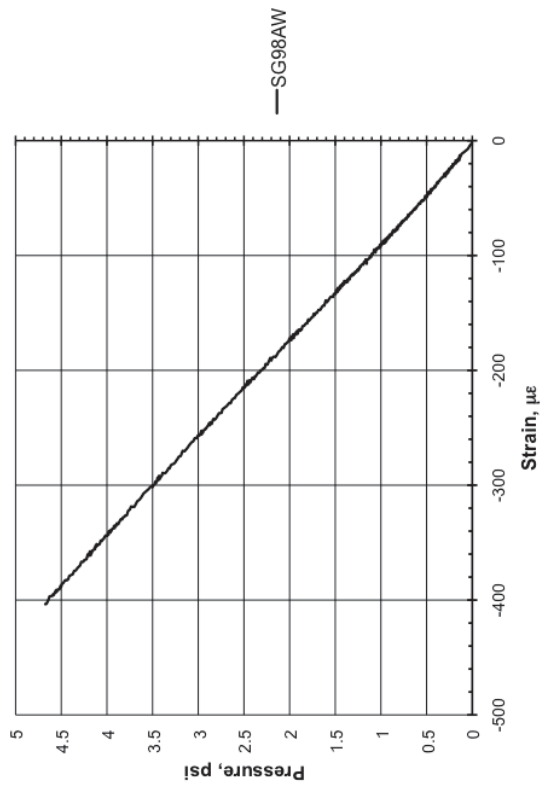


Figure A109. Checkout test 1, strain gage SG98AW.

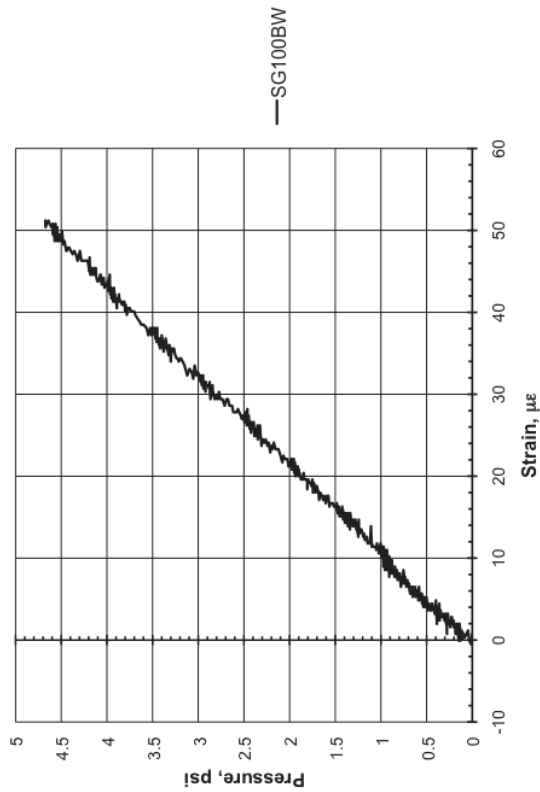


Figure A111. Checkout test 1, strain gage SG100BW.

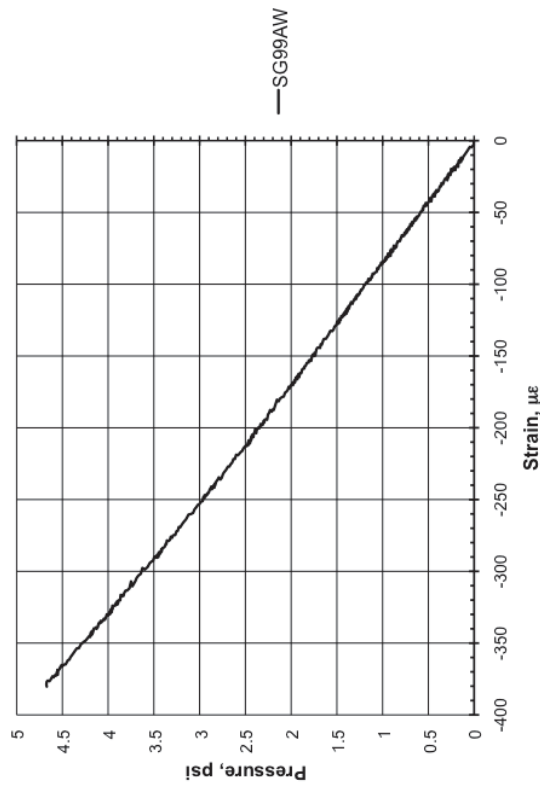


Figure A110. Checkout test 1, strain gage SG99AW.

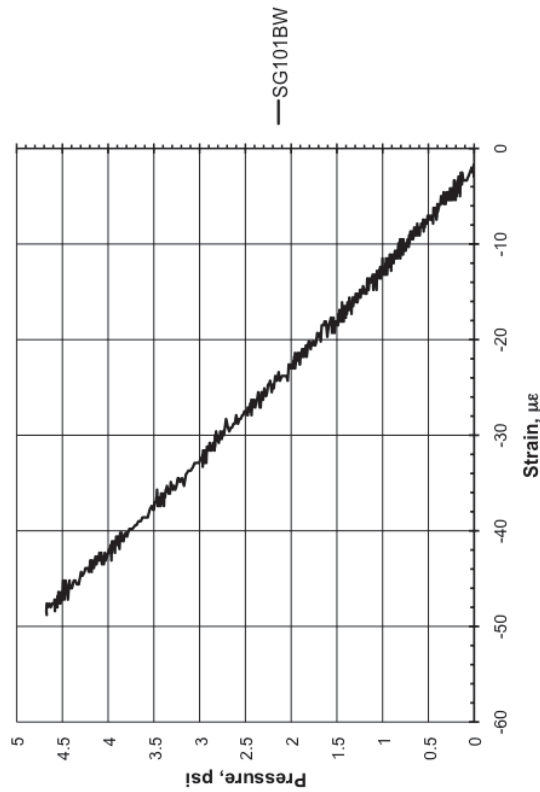


Figure A112. Checkout test 1, strain gage SG101BW.

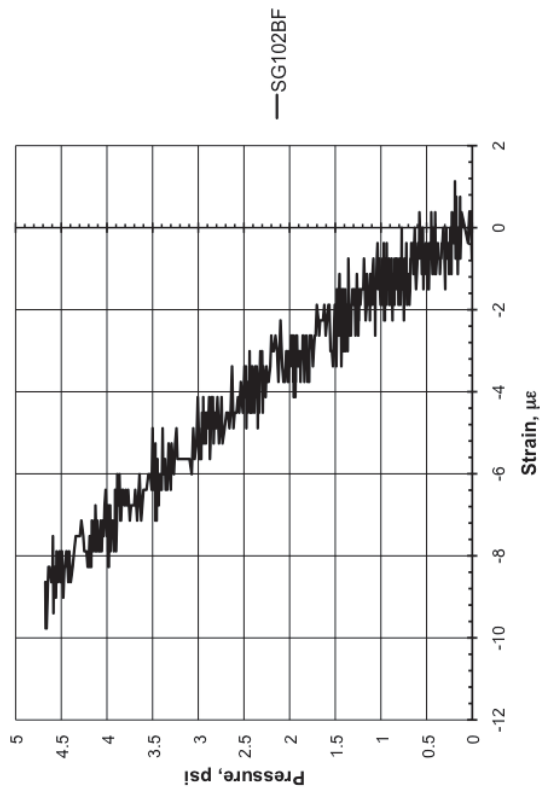


Figure A113. Checkout test 1, strain gage SG102BF.

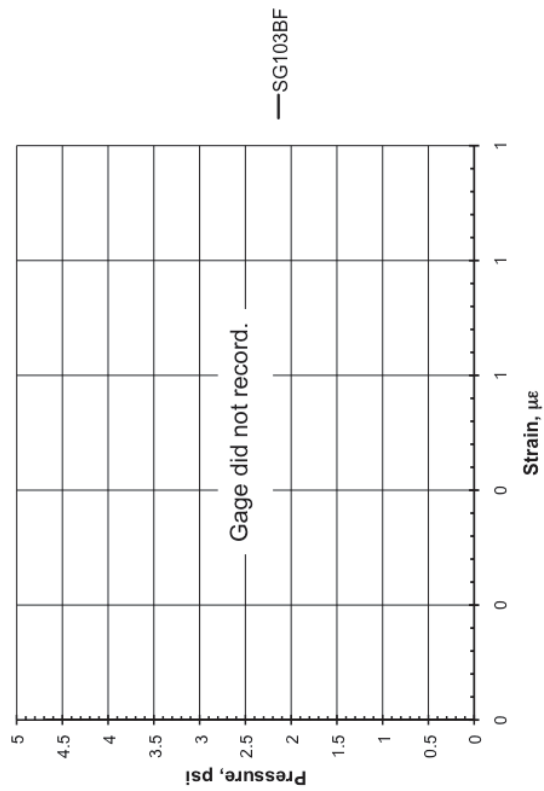


Figure A114. Checkout test 1, strain gage SG103BF.

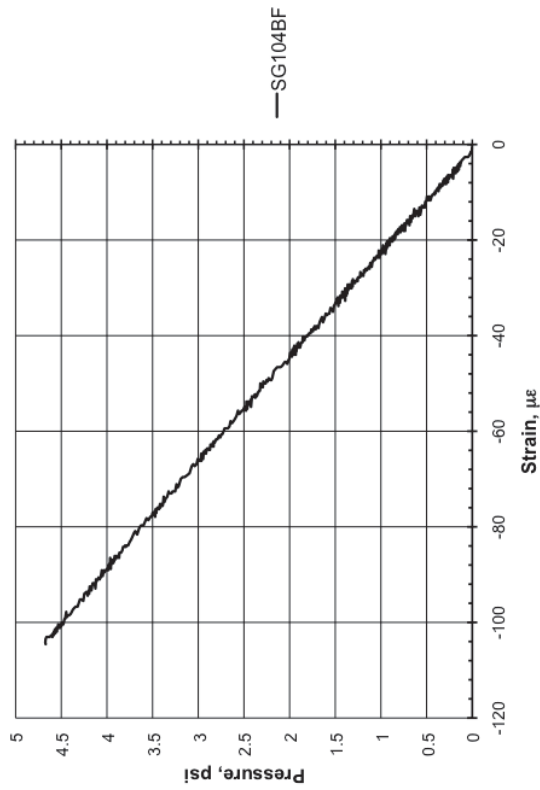


Figure A115. Checkout test 1, strain gage SG104BF.

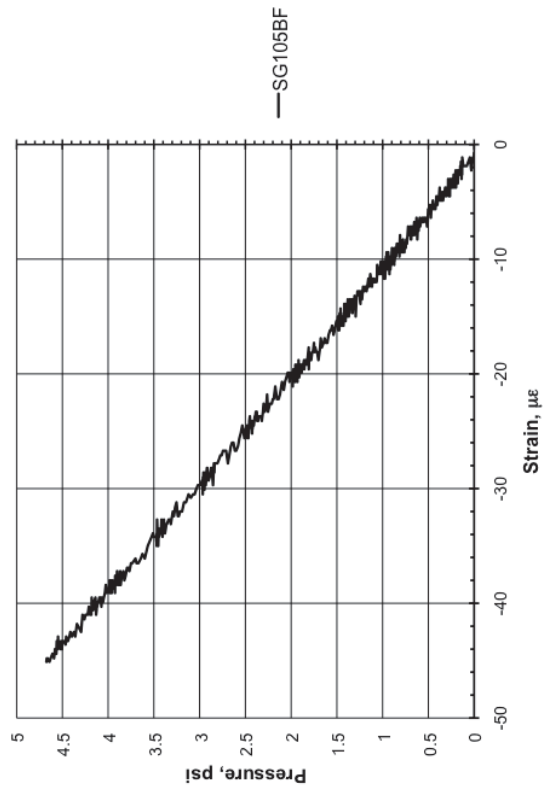


Figure A116. Checkout test 1, strain gage SG105BF.

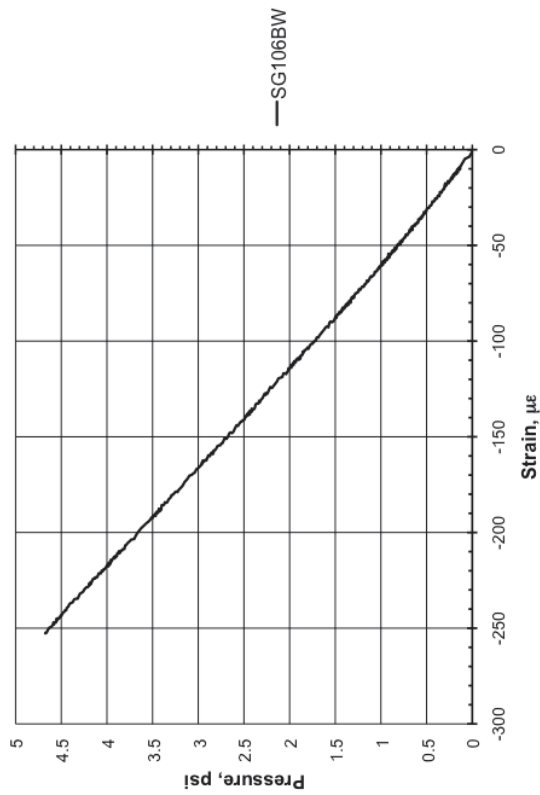


Figure A117. Checkout test 1, strain gage SG106BW.

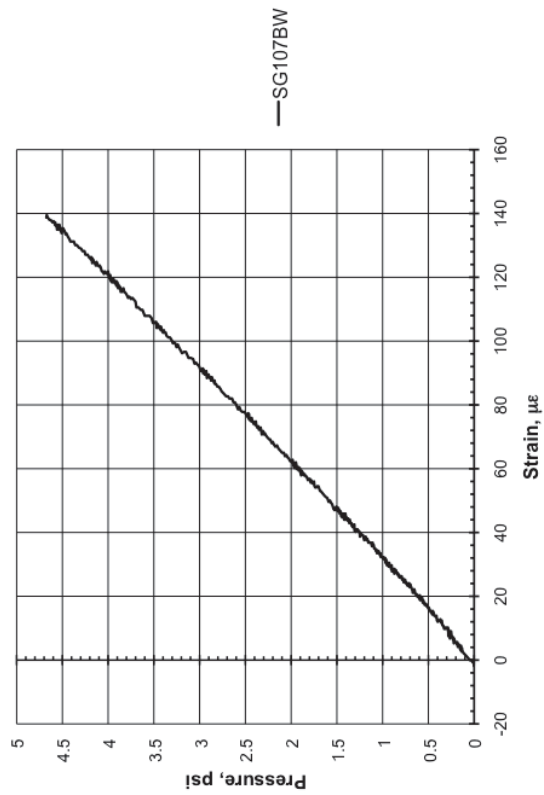


Figure A118. Checkout test 1, strain gage SG107BW.

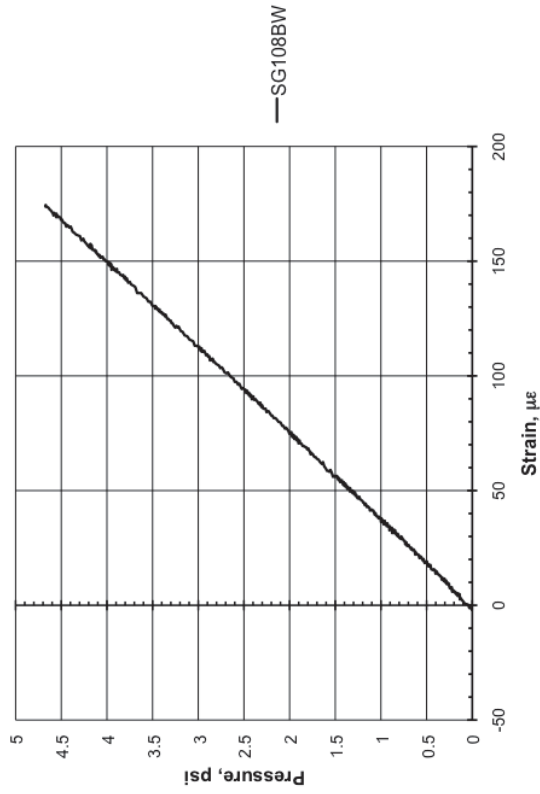


Figure A119. Checkout test 1, strain gage SG108BW.

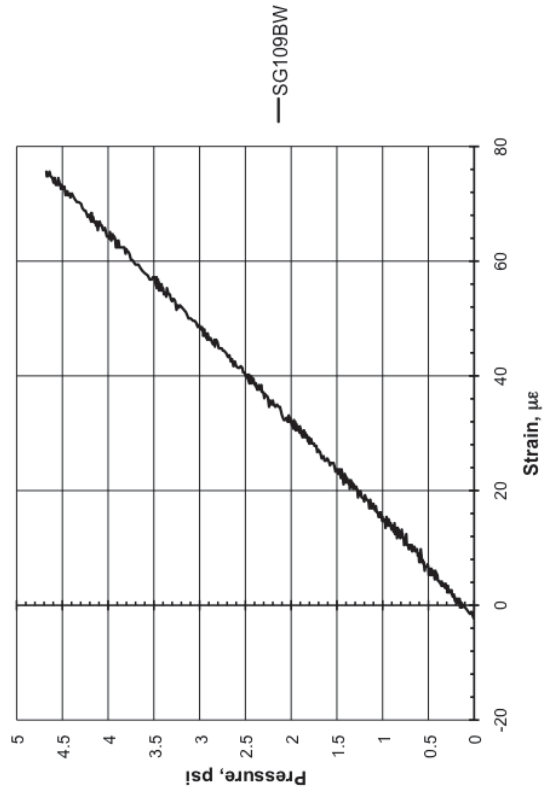


Figure A120. Checkout test 1, strain gage SG109BW.

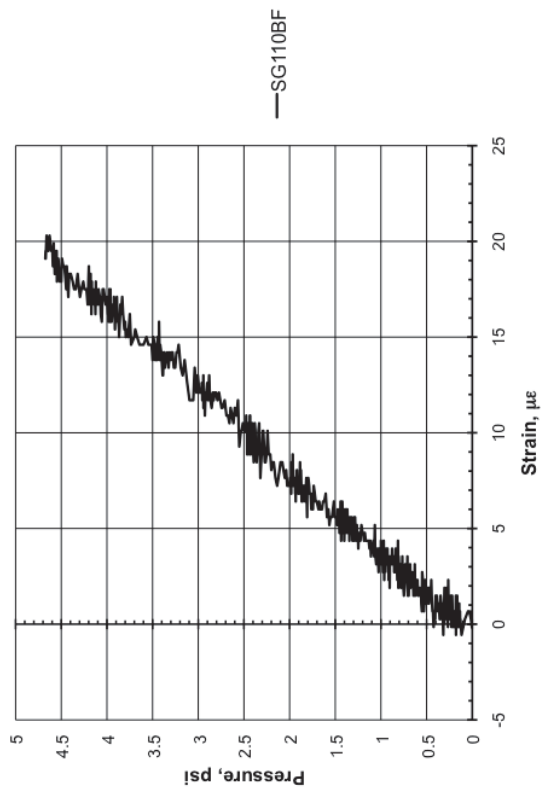


Figure A121. Checkout test 1, strain gage SG110BF.

A32

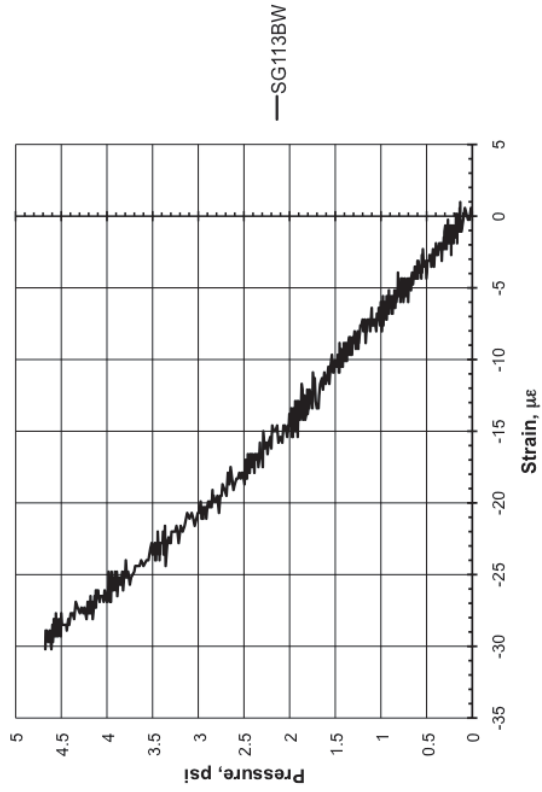


Figure A123. Checkout test 1, strain gage SG113BW.

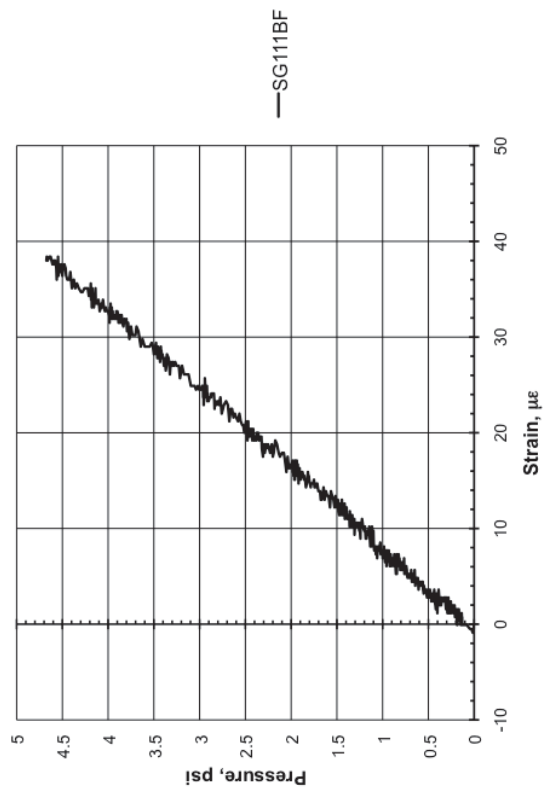


Figure A122. Checkout test 1, strain gage SG111BF.

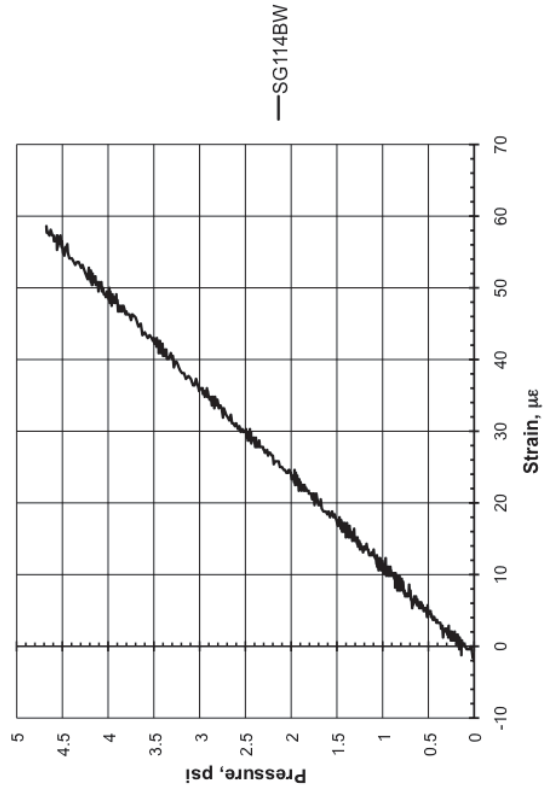


Figure A124. Checkout test 1, strain gage SG114BW.

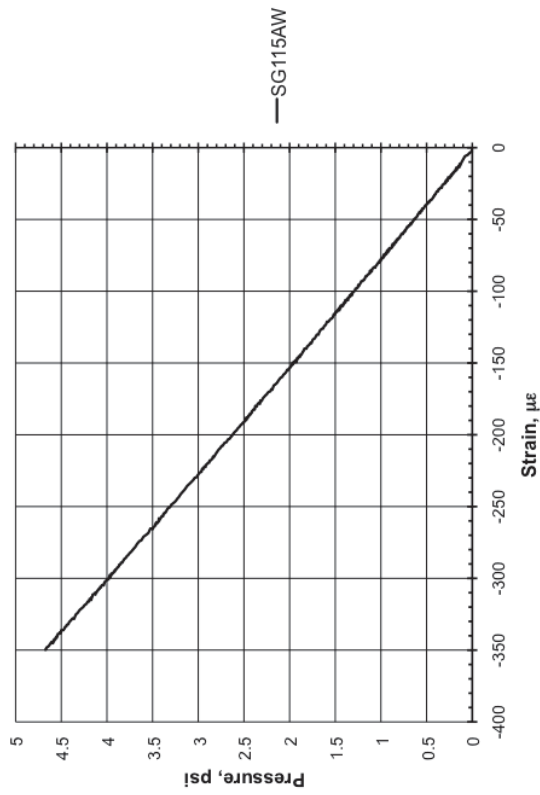


Figure A125. Checkout test 1, strain gage SG115AW.

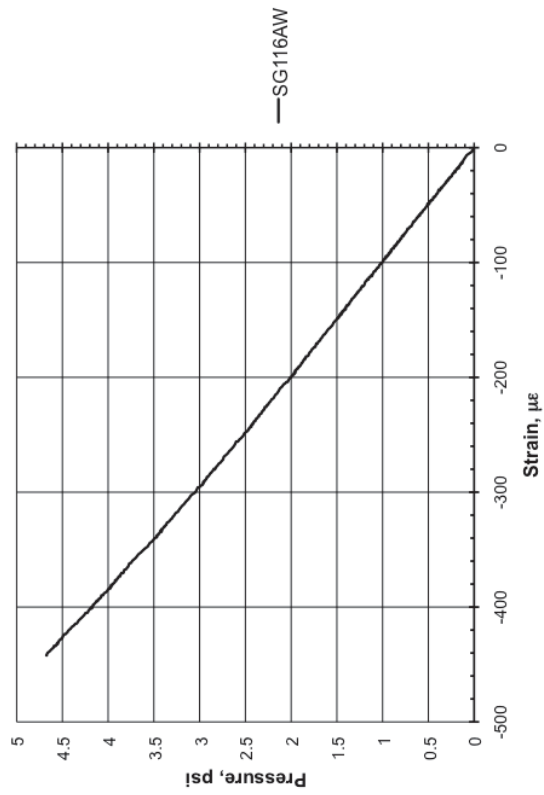


Figure A126. Checkout test 1, strain gage SG116AW.

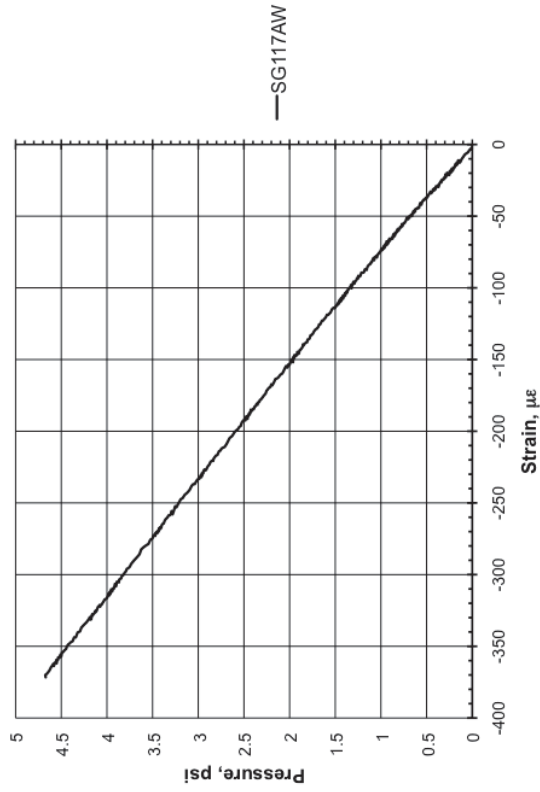


Figure A127. Checkout test 1, strain gage SG117AW.

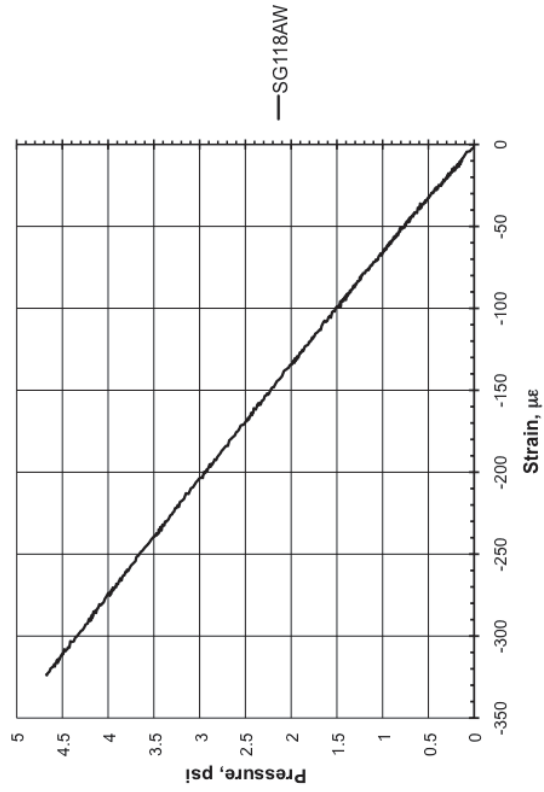


Figure A128. Checkout test 1, strain gage SG118AW.



**Appendix B:**  
**Checkout Test 2 DCDT and Strain Gage Plots**

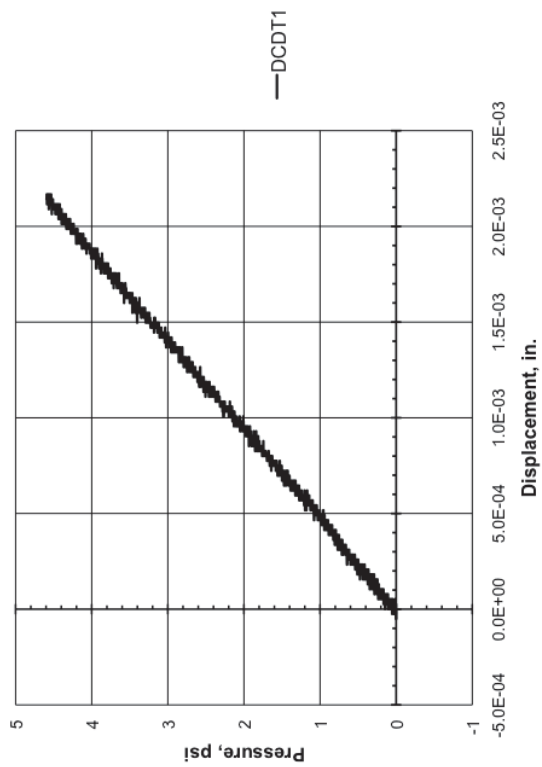


Figure B1. Checkout test 2, DCDT1.

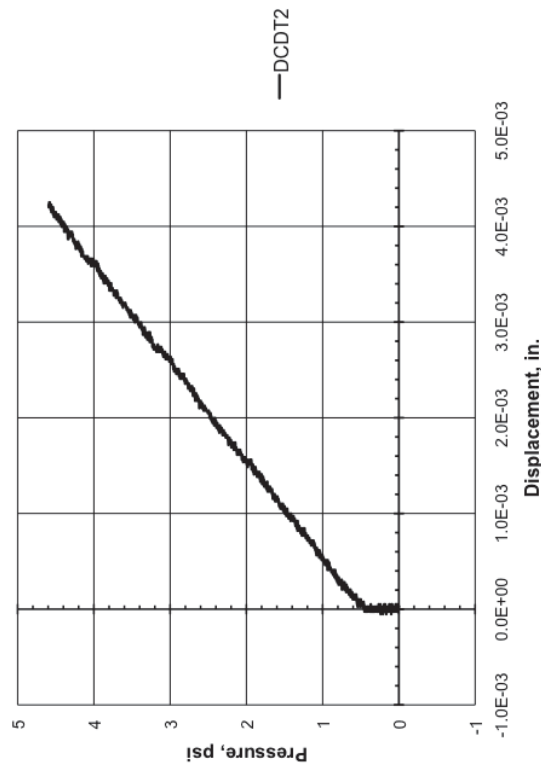


Figure B2. Checkout test 2, DCDT2.

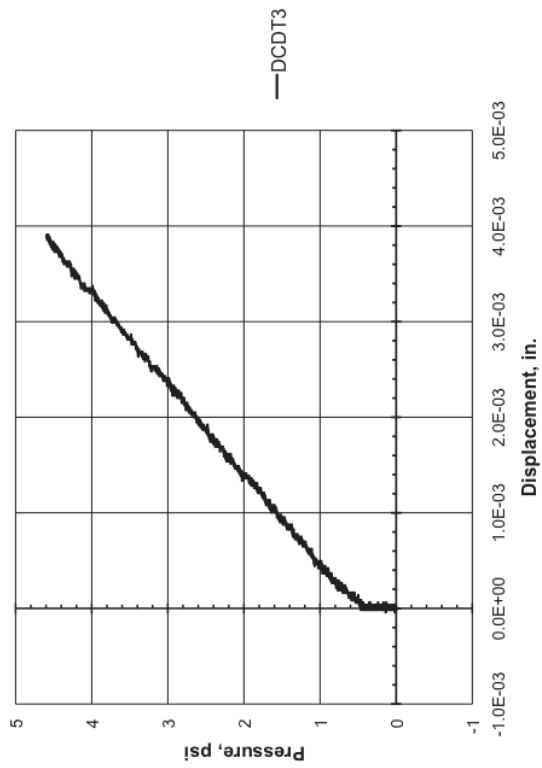


Figure B3. Checkout test 2, DCDT3.

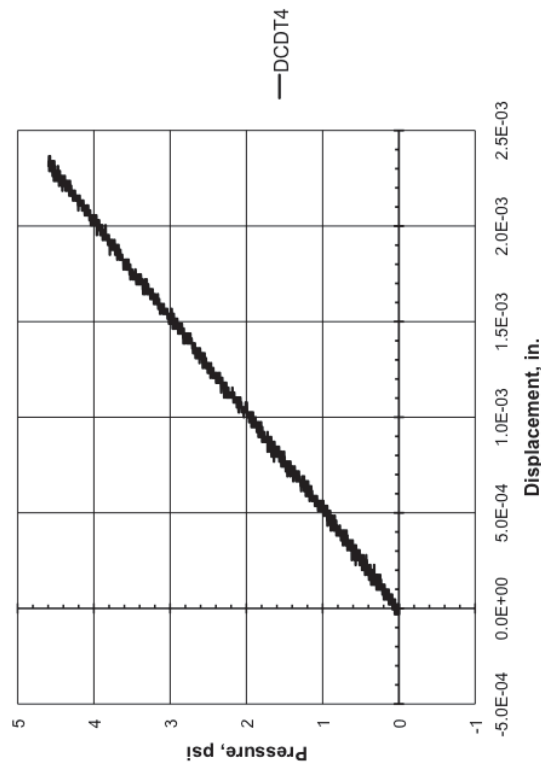


Figure B4. Checkout test 2, DCDT4.

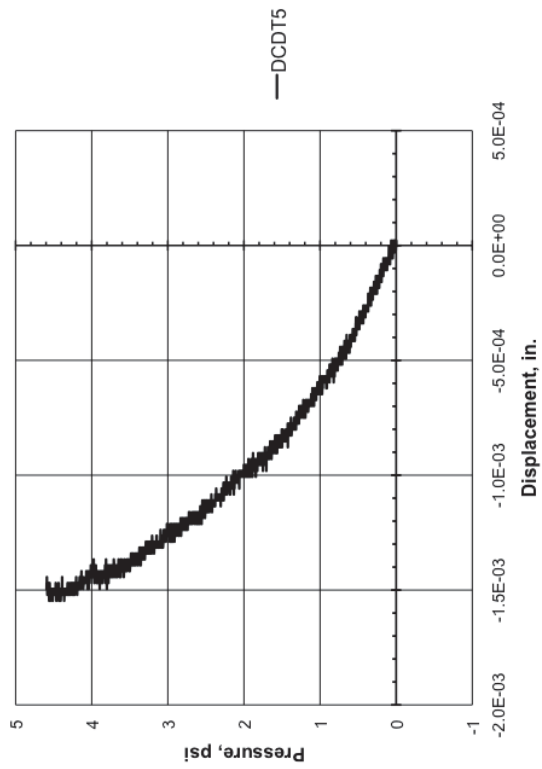


Figure B5. Checkout test 2, DCDT5.

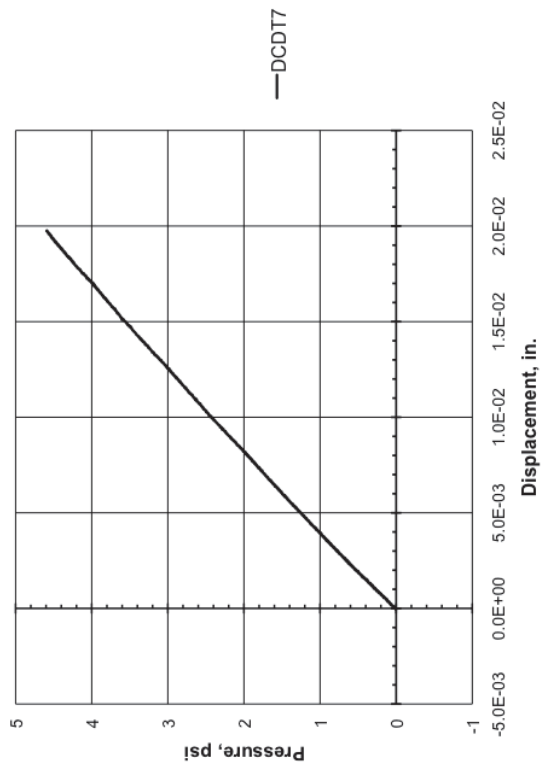


Figure B7. Checkout test 2, DCDT7.

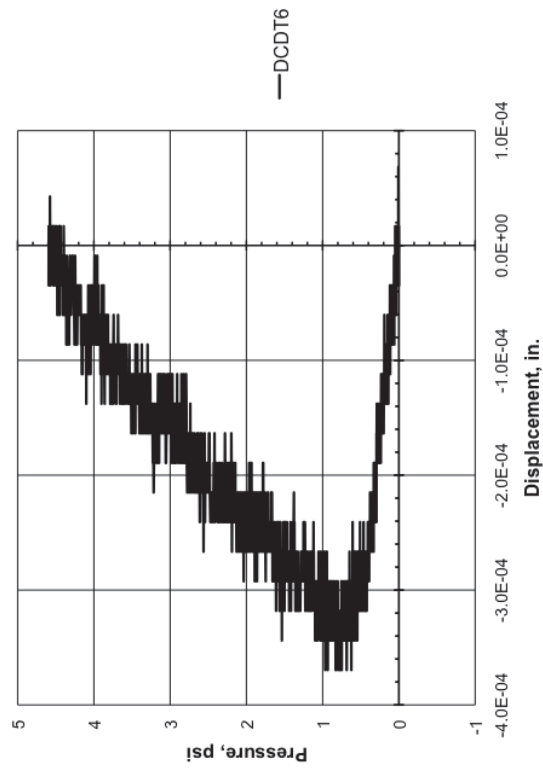


Figure B6. Checkout test 2, DCDT6.

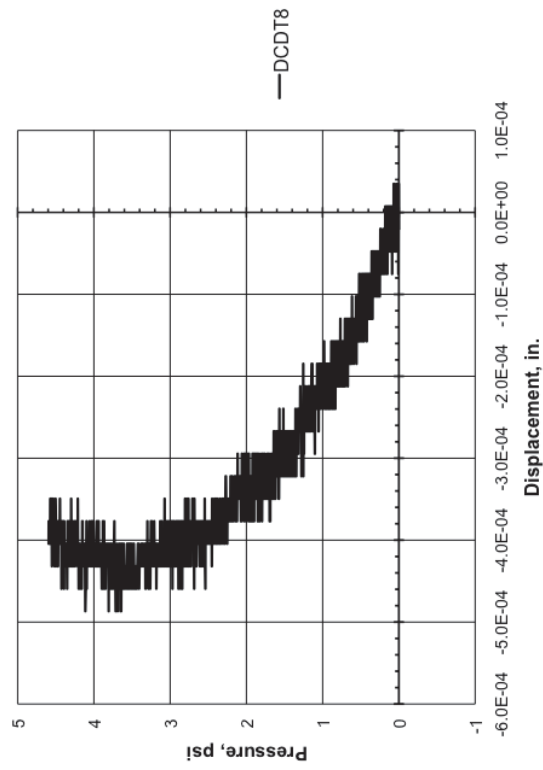


Figure B8. Checkout test 2, DCDT8.

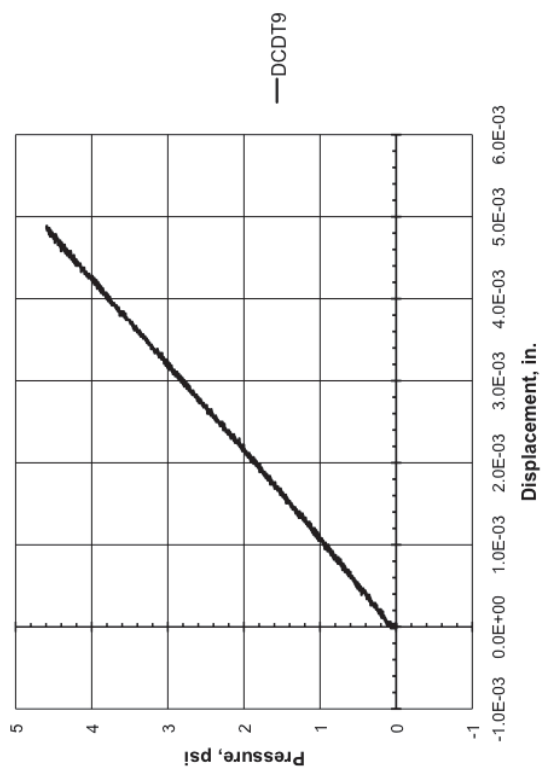


Figure B9. Checkout test 2, DCDT9.

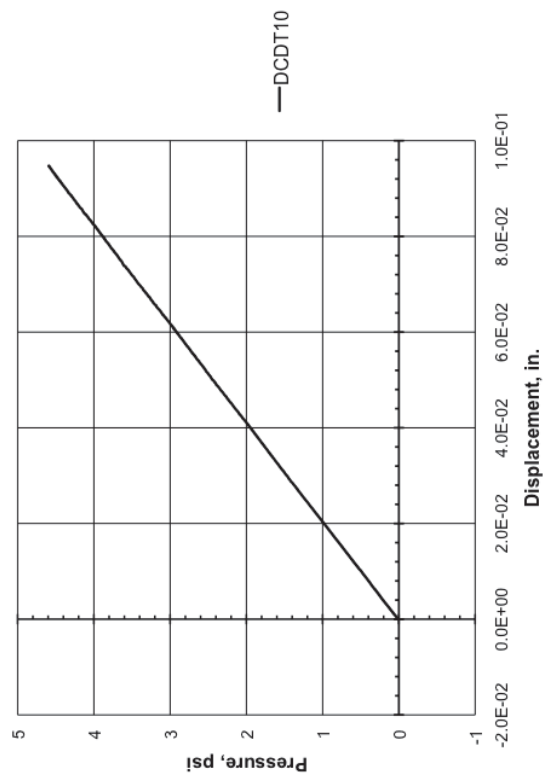


Figure B10. Checkout test 2, DCDT10.

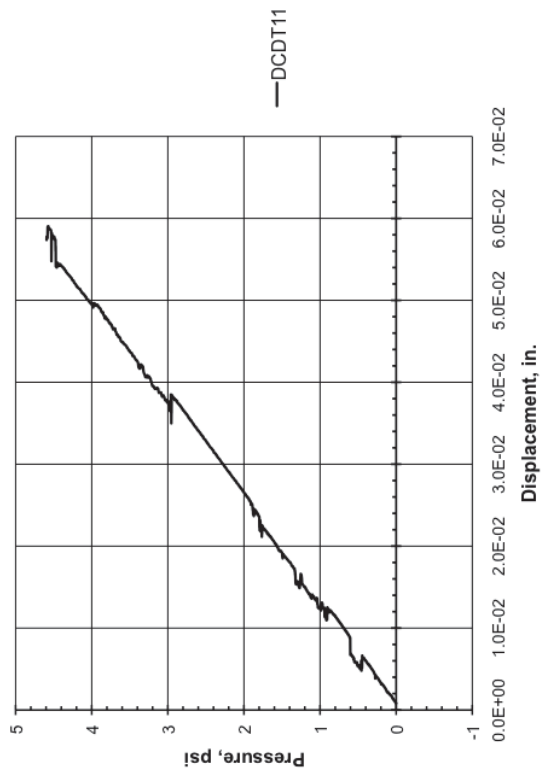


Figure B11. Checkout test 2, DCDT11.

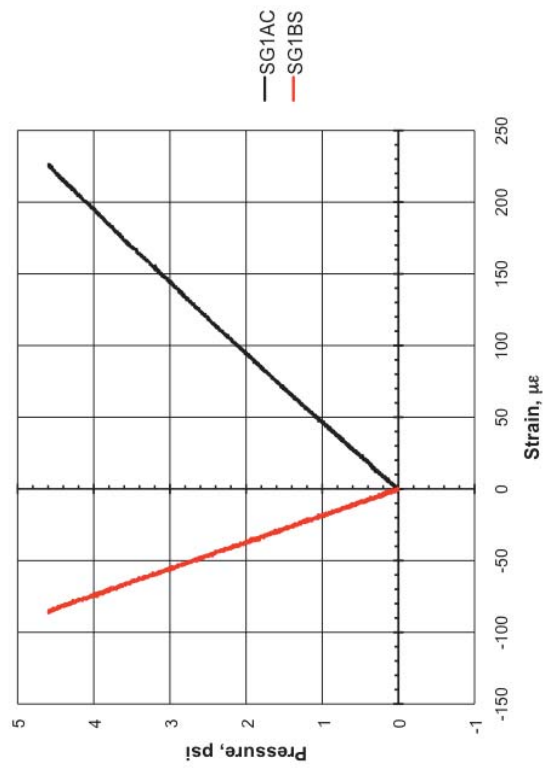


Figure B12. Checkout test 2, strain gages SG1AC and SG1BS.

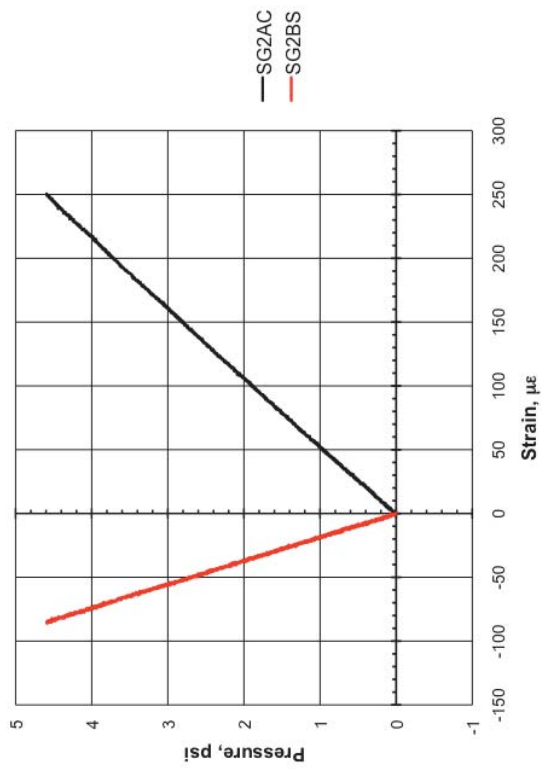


Figure B13. Checkout test 2, strain gages SG2AC and SG2BS.

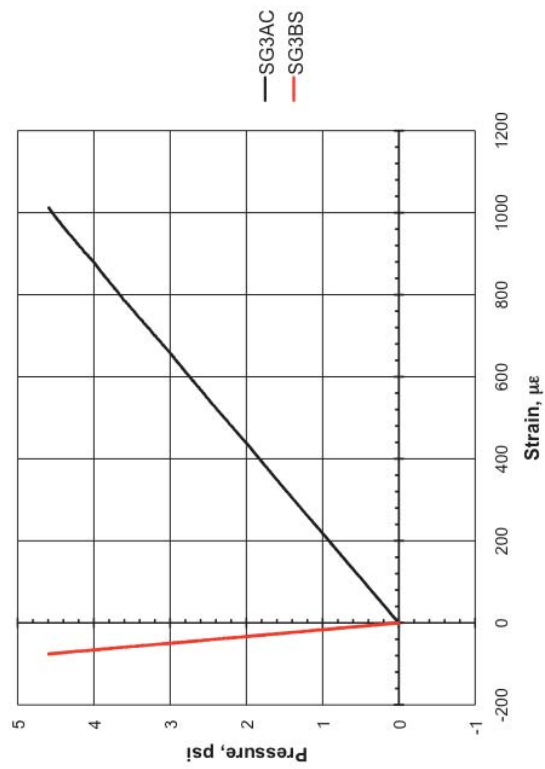


Figure B14. Checkout test 2, strain gages SG3AC and SG3BS.

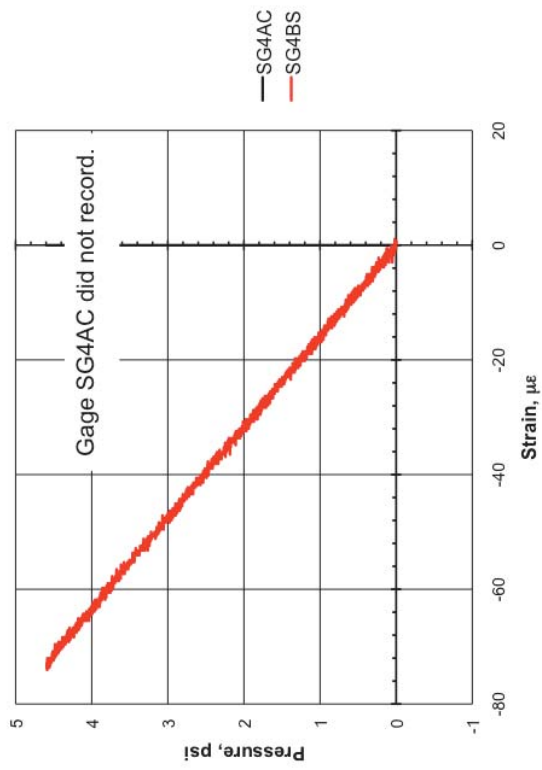


Figure B15. Checkout test 2, strain gages SG4AC and SG4BS.

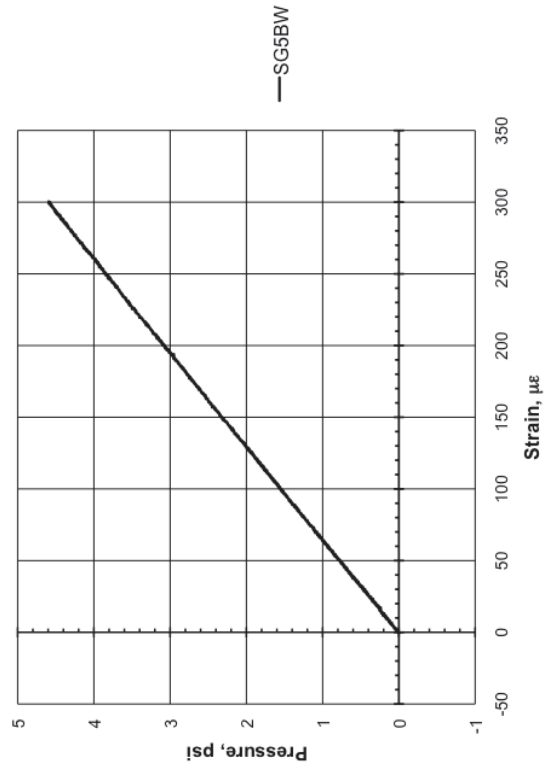


Figure B16. Checkout test 2, strain gage SG5BW.

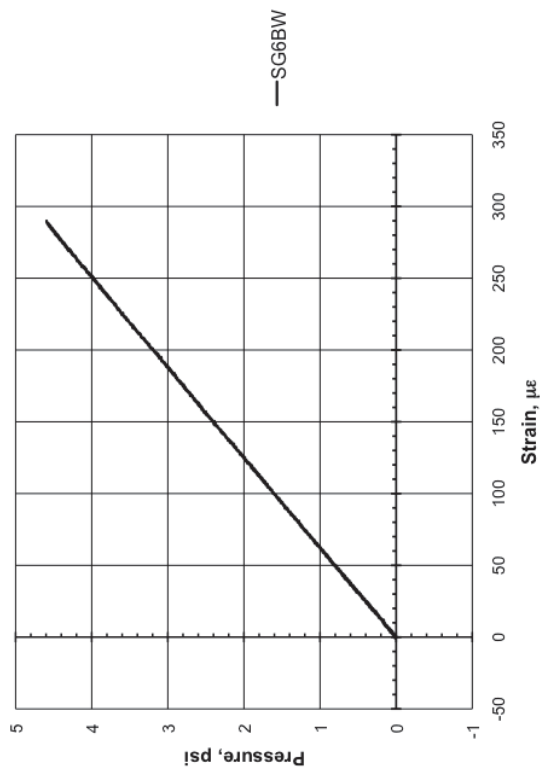


Figure B17. Checkout test 2, strain gage SG6BW.

B6

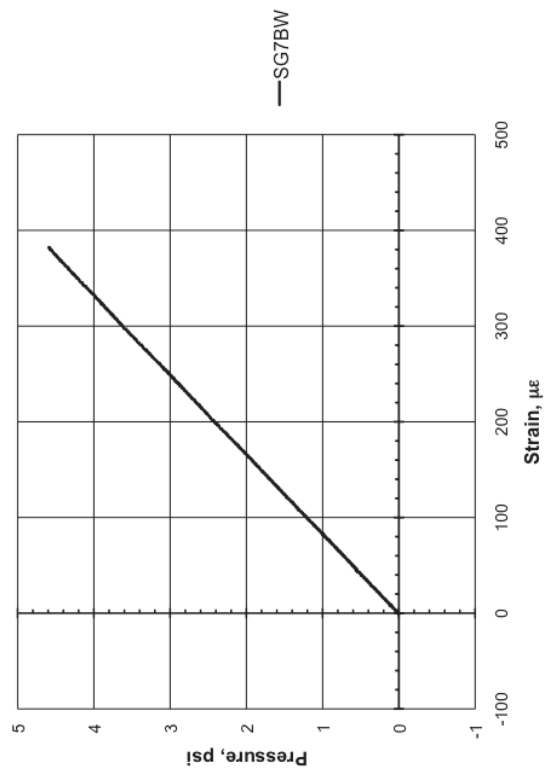


Figure B18. Checkout test 2, strain gage SG7BW.

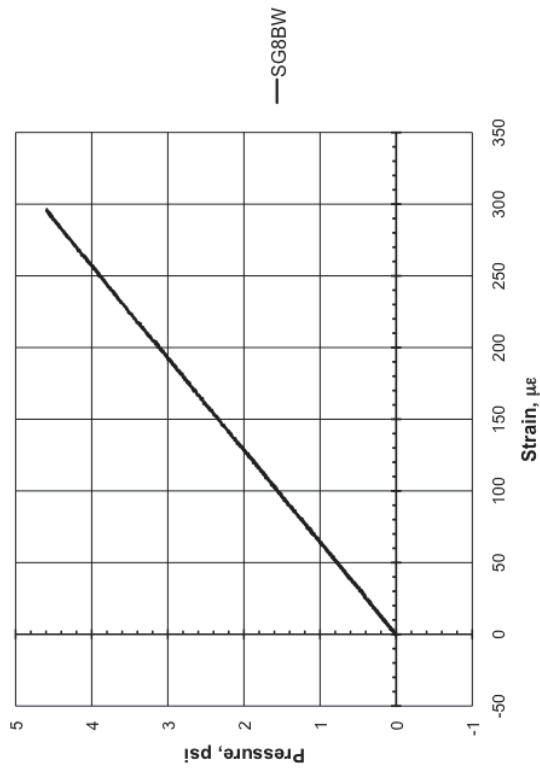


Figure B19. Checkout test 2, strain gage SG8BW.

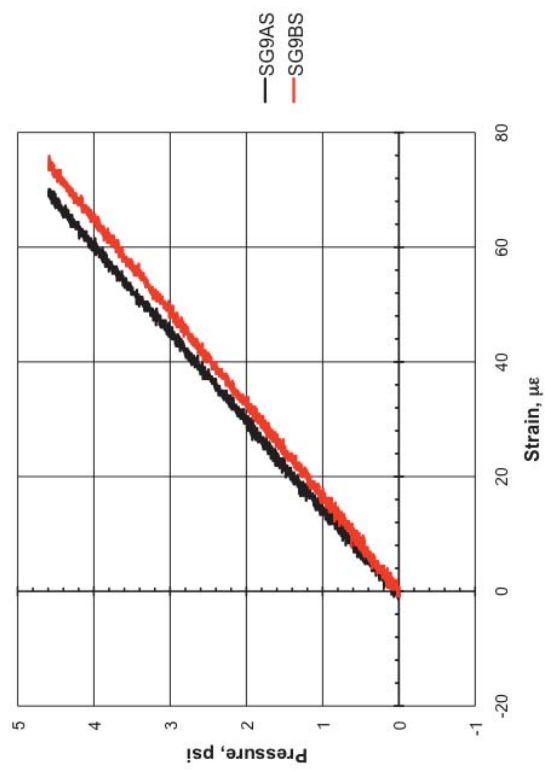


Figure B20. Checkout test 2, strain gages SG9AS and SG9BS.

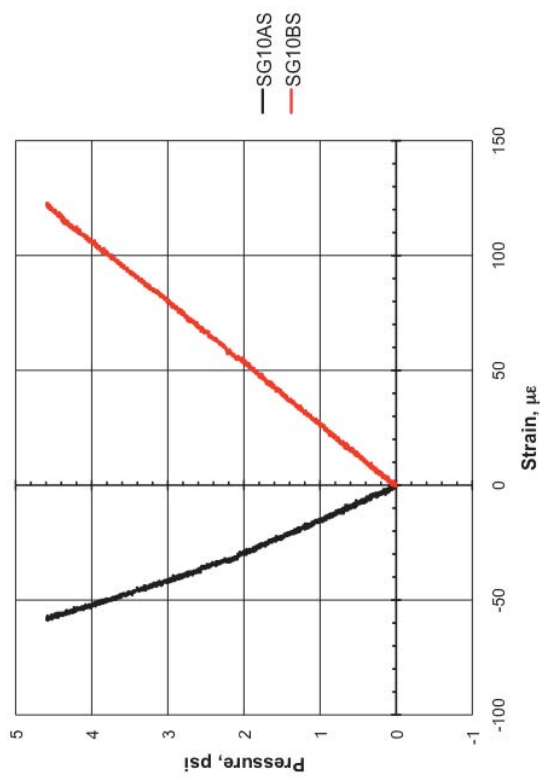


Figure B21. Checkout test 2, strain gages SG10AS and SG10BS.

B7

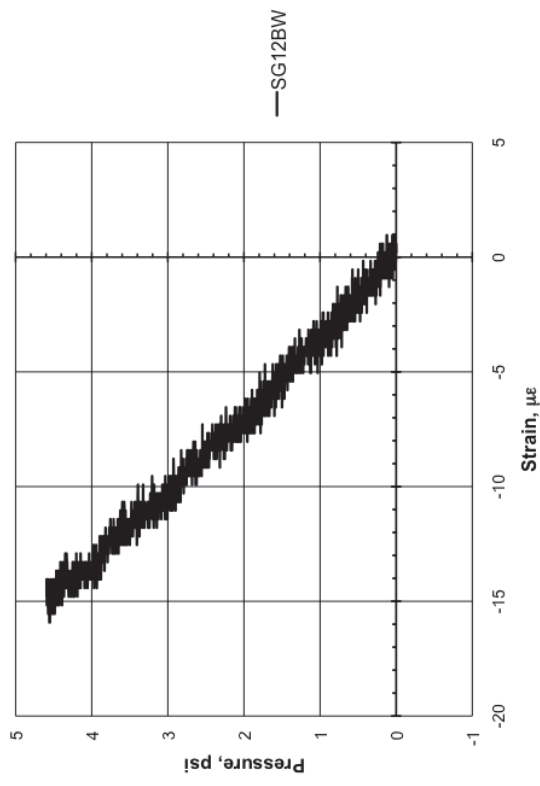


Figure B23. Checkout test 2, strain gage SG12BW.

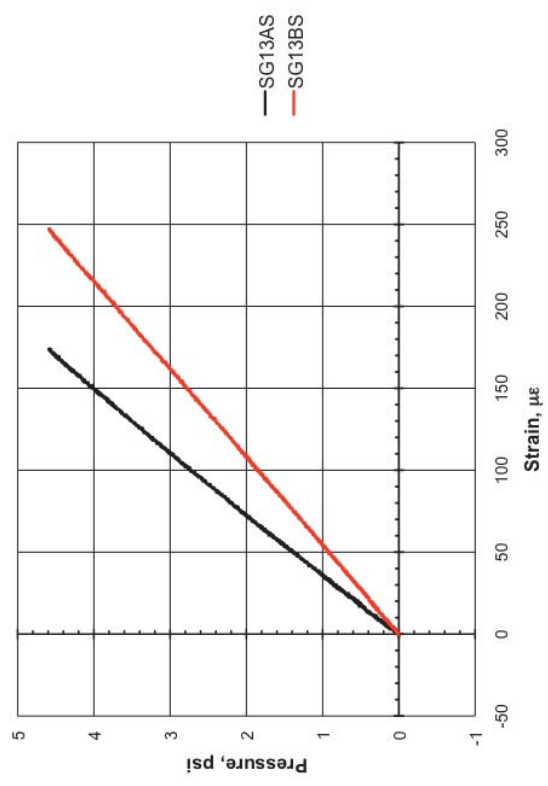


Figure B24. Checkout test 2, strain gages SG13AS and SG13BS.

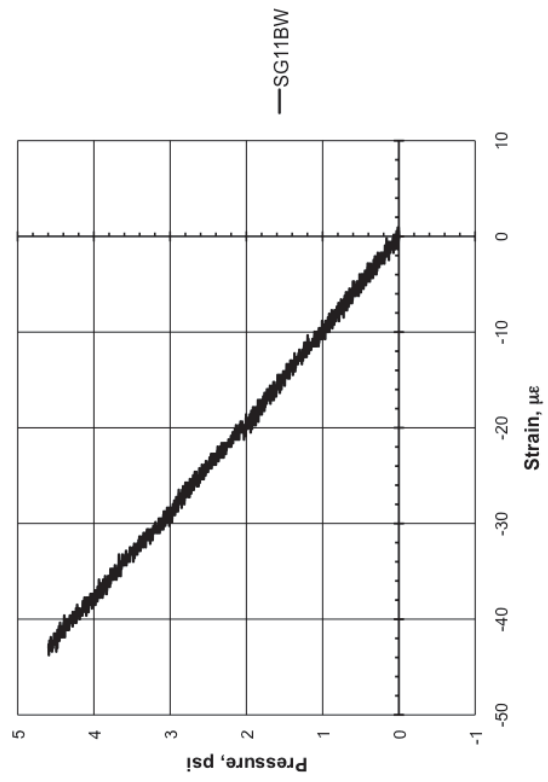


Figure B22. Checkout test 2, strain gage SG11BW.



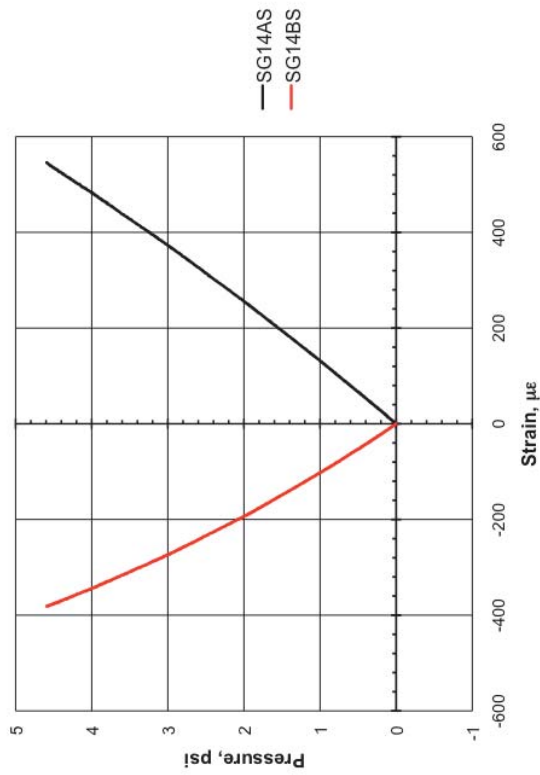


Figure B25. Checkout test 2, strain gages SG14AS and SG14BS.

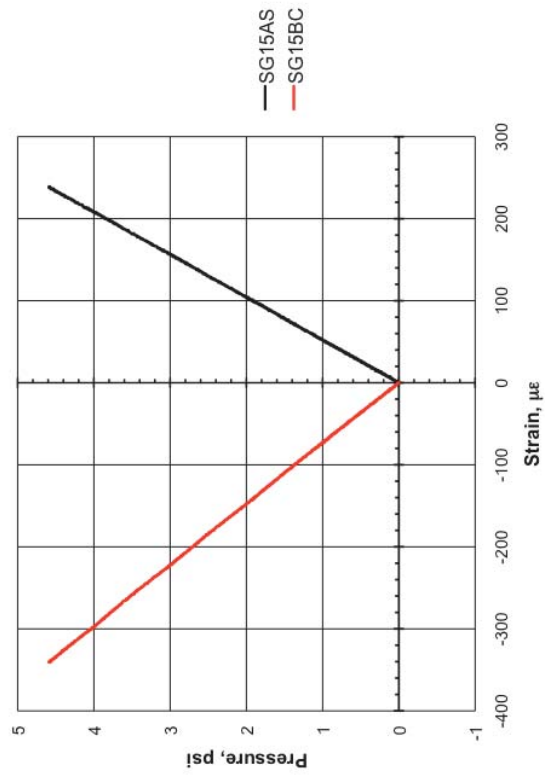


Figure B26. Checkout test 2, strain gages SG15AS and SG15BC.

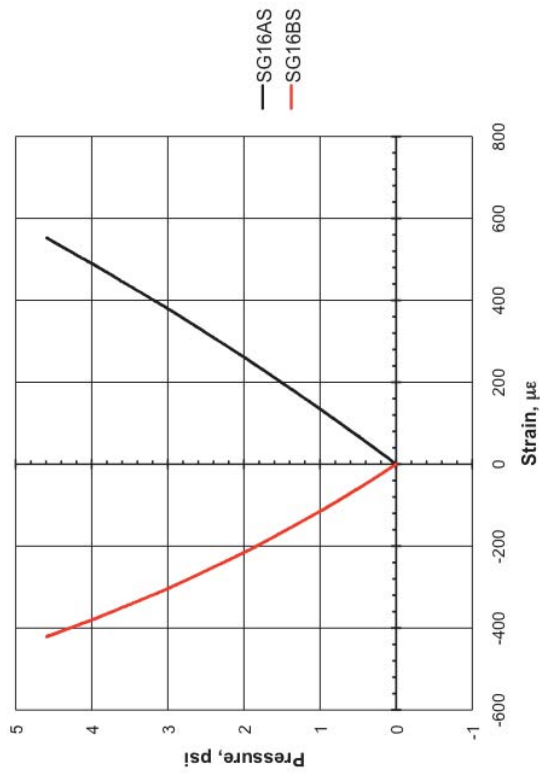


Figure B27. Checkout test 2, strain gages SG16AS and SG16BS.

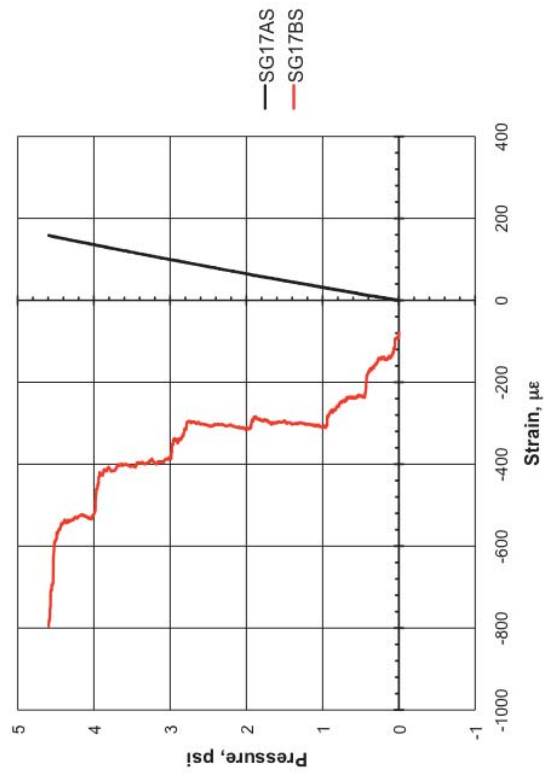


Figure B28. Checkout test 2, strain gages SG17AS and 17BS.

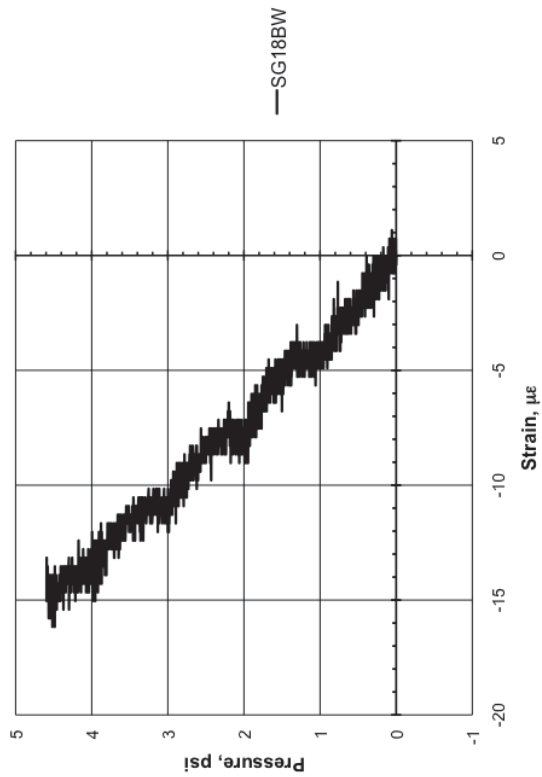


Figure B29. Checkout test 2, strain gage SG18BW.

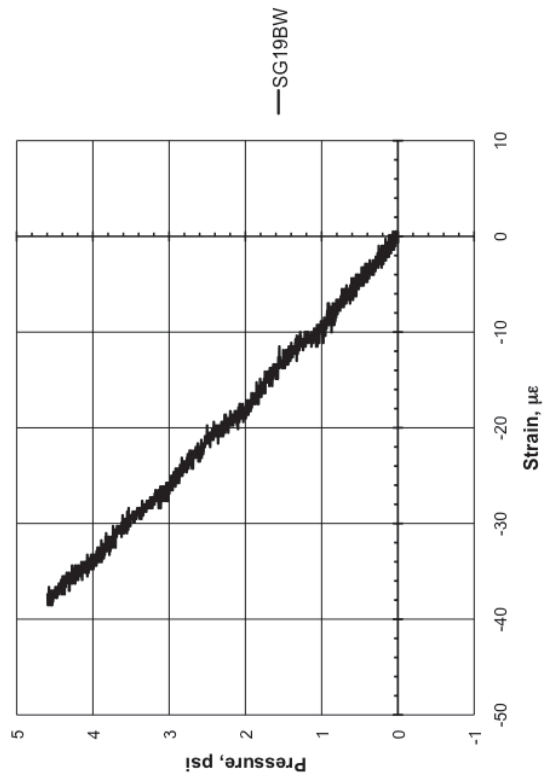


Figure B30. Checkout test 2, strain gage SG19BW.

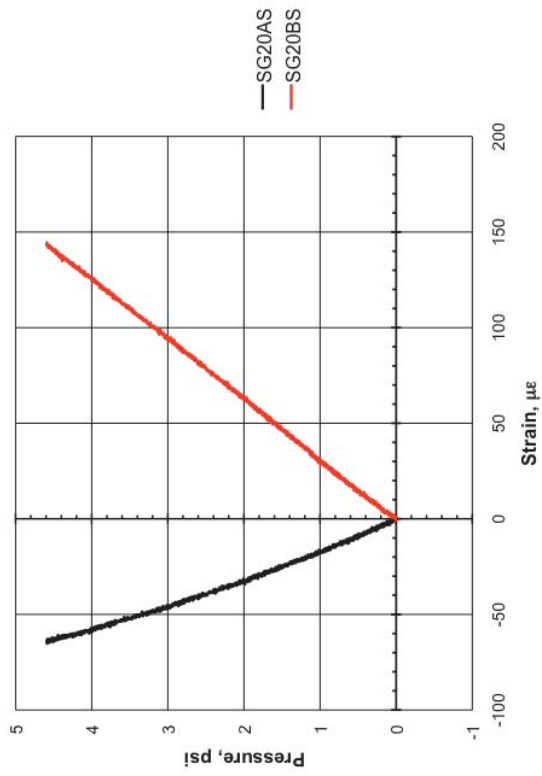


Figure B31. Checkout test 2, strain gages SG20AS and SG20BS.

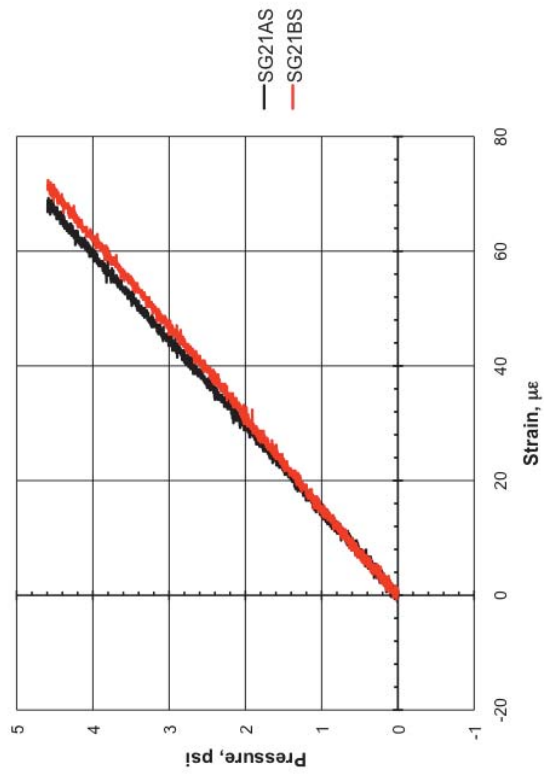


Figure B32. Checkout test 2, strain gages SG21AS and SG21BS.

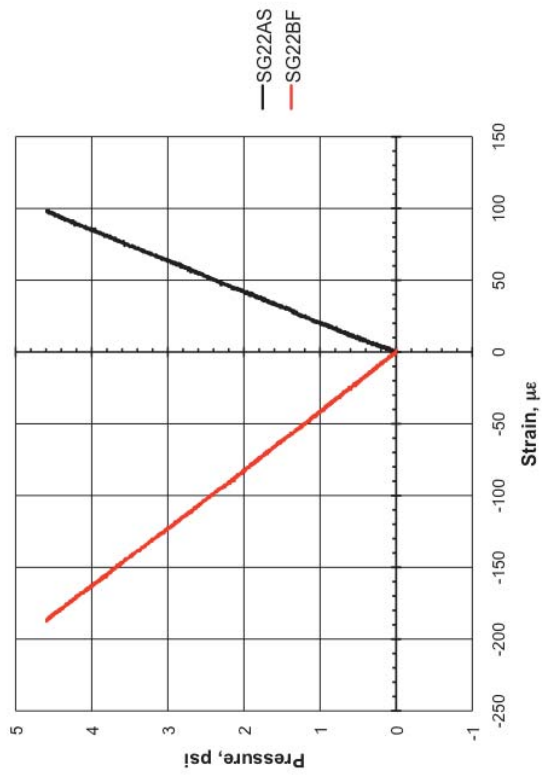


Figure B33. Checkout test 2, strain gages SG22AS and SG22BF.

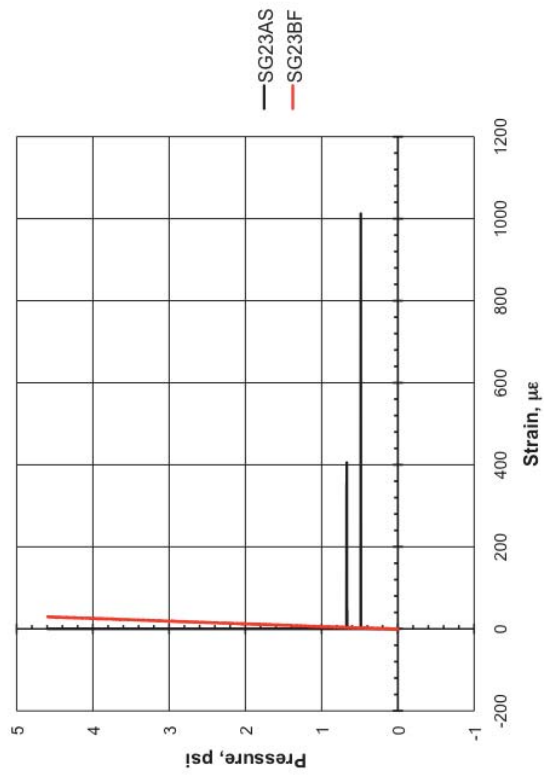


Figure B34. Checkout test 2, strain gages SG23AS and SG23BF.

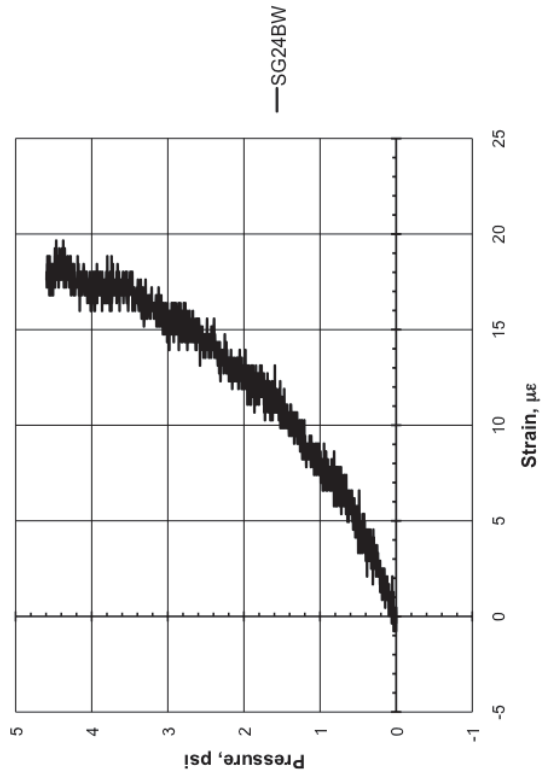


Figure B35. Checkout test 2, strain gage SG24BW.

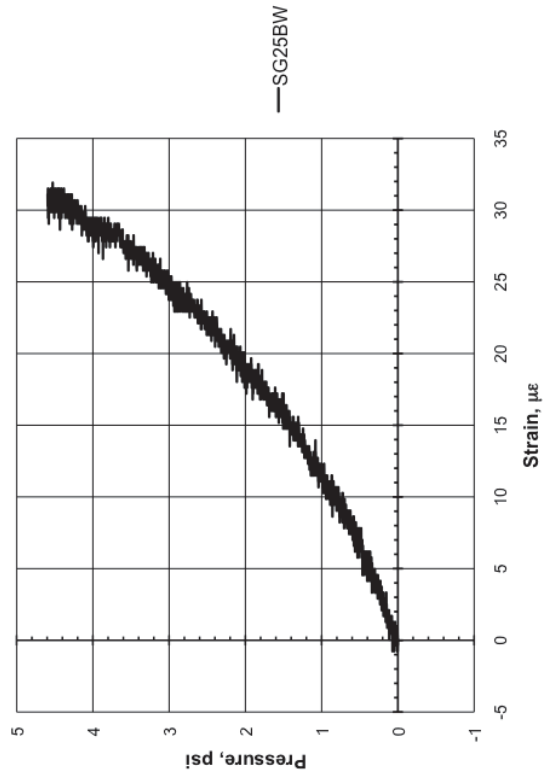


Figure B36. Checkout test 2, strain gage SG25BW.

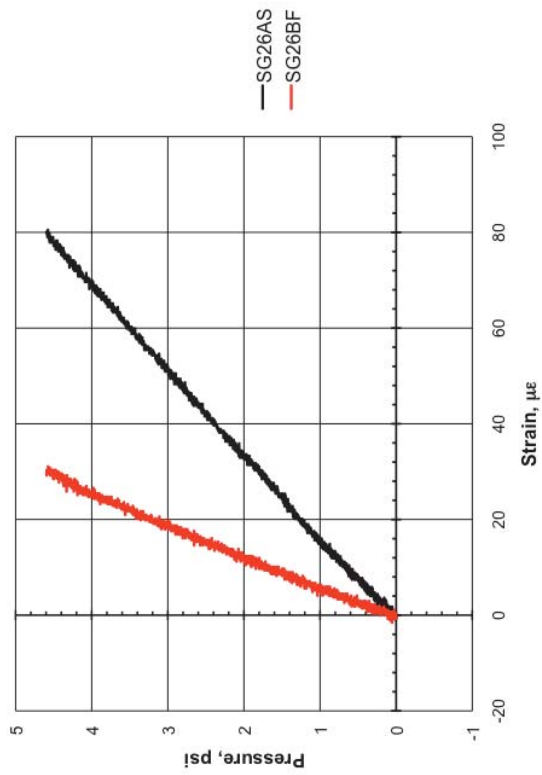


Figure B37. Checkout test 2, strain gages SG26AS and SG26BF.

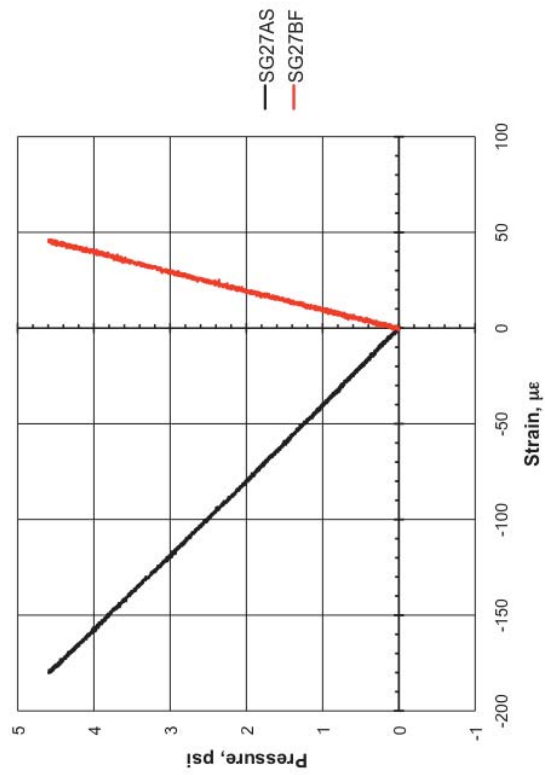


Figure B38. Checkout test 2, strain gages SG27AS and SG27BF.

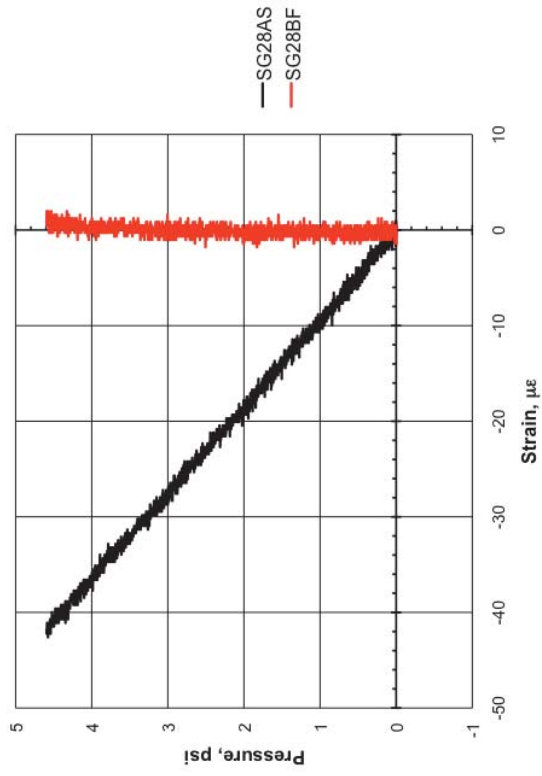


Figure B39. Checkout test 2, strain gages SG28AS and SG28BF.

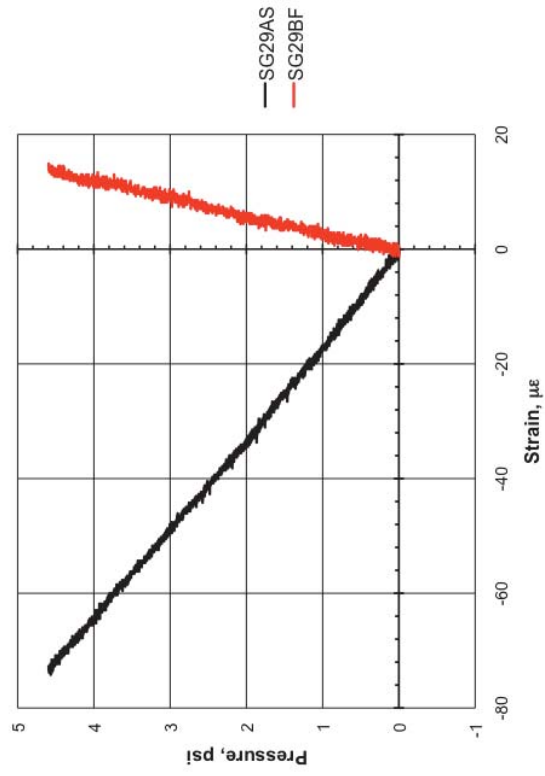


Figure B40. Checkout test 2, strain gages SG29AS and SG29BF.

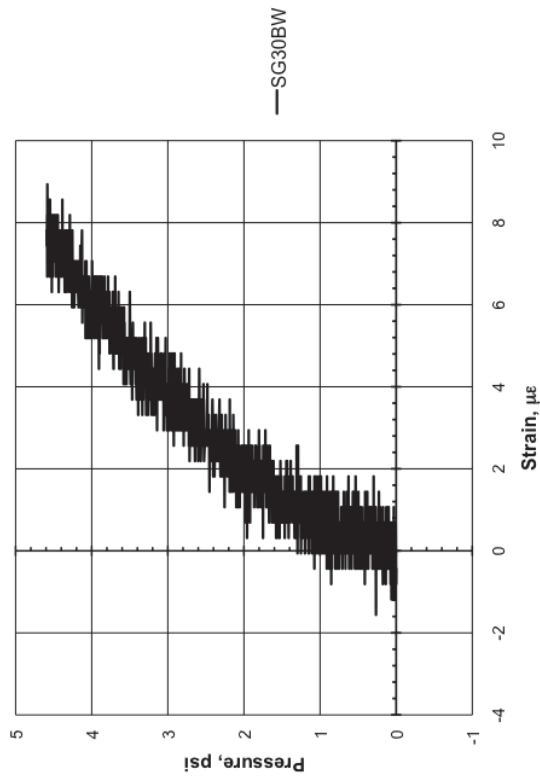


Figure B41. Checkout test 2, strain gage SG30BW.

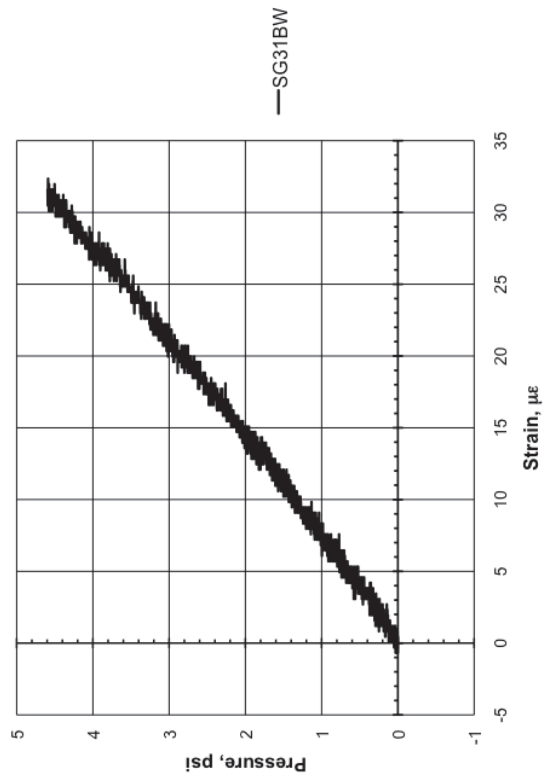


Figure B42. Checkout test 2, strain gage SG31BW.

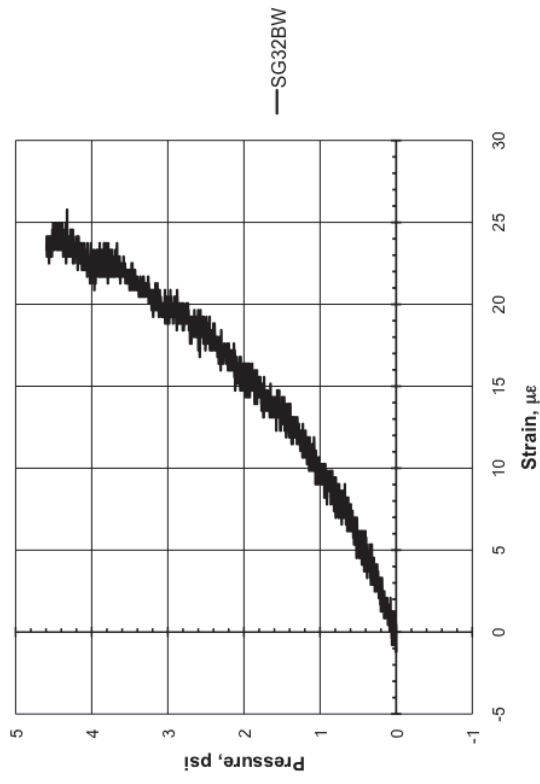


Figure B43. Checkout test 2, strain gage SG32BW.

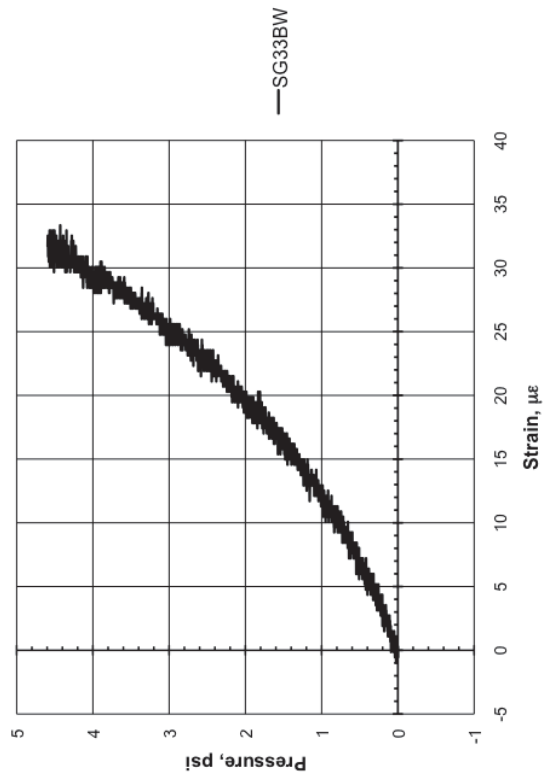


Figure B44. Checkout test 2, strain gage SG33BW.

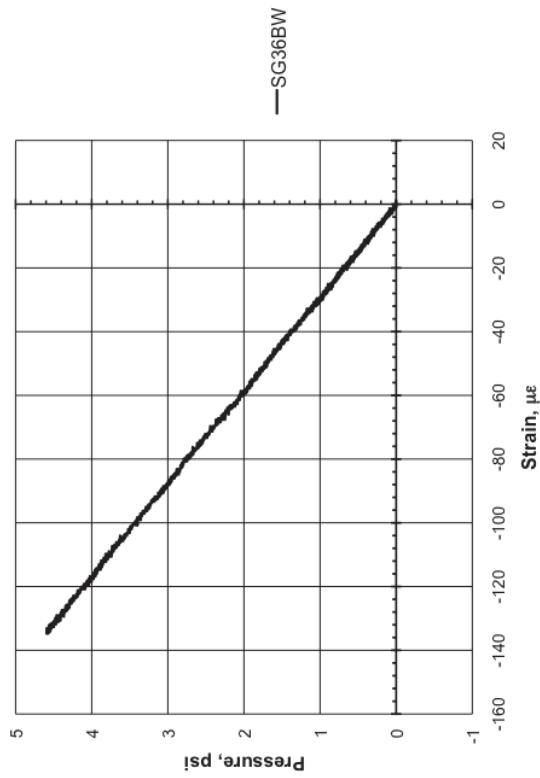


Figure B47. Checkout test 2, strain gage SG36BW.

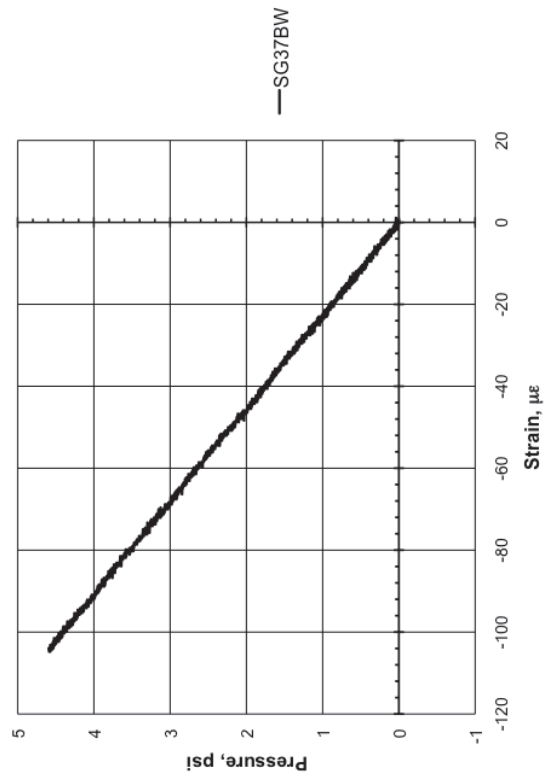


Figure B48. Checkout test 2, strain gage SG37BW.

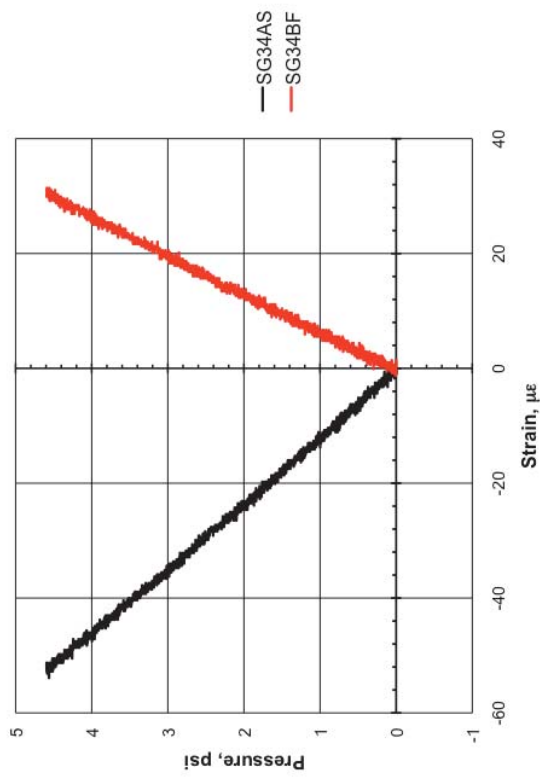


Figure B45. Checkout test 2, strain gages SG34AS and SG34BF.

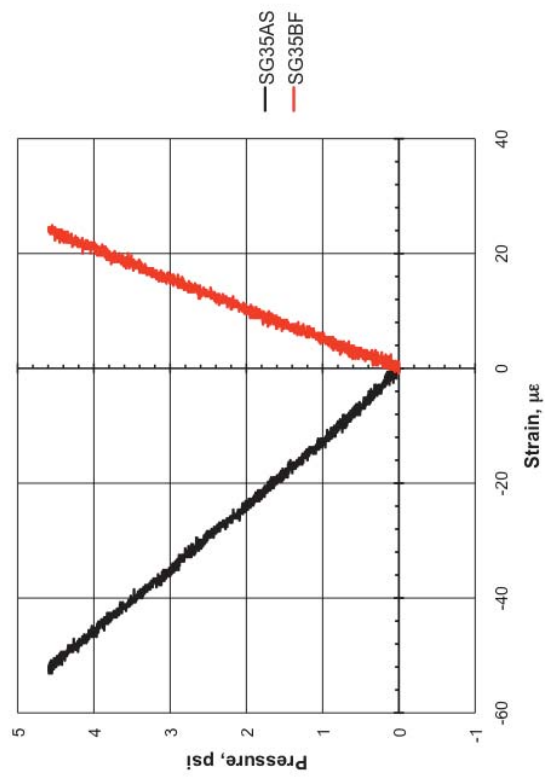


Figure B46. Checkout test 2, strain gages SG35AS and SG35BF.

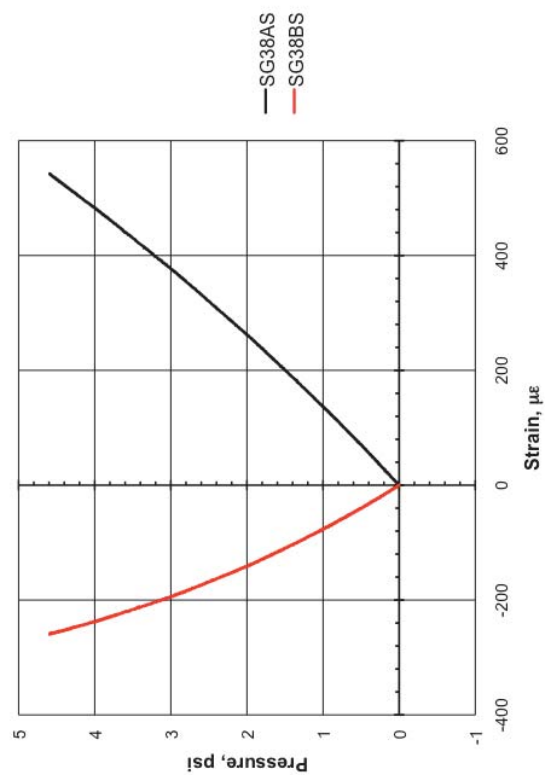


Figure B49. Checkout test 2, strain gages SG38AS and SG38BS.

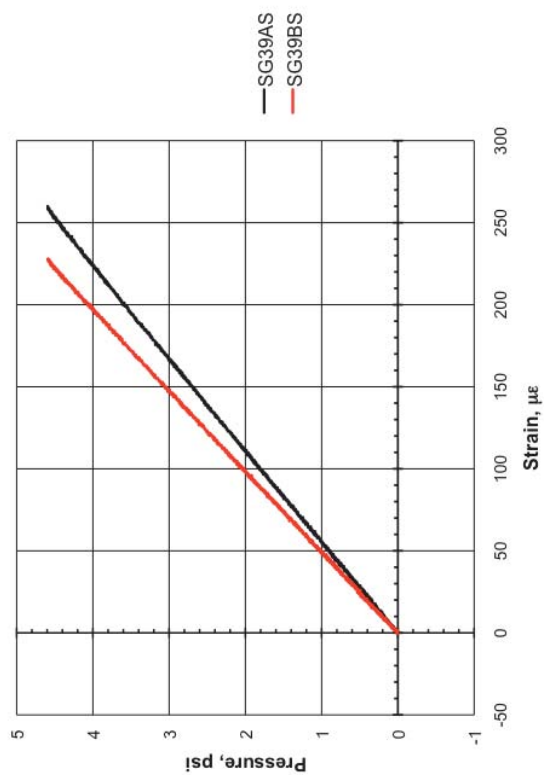


Figure B50. Checkout test 2, strain gages SG39AS and SG39BS.

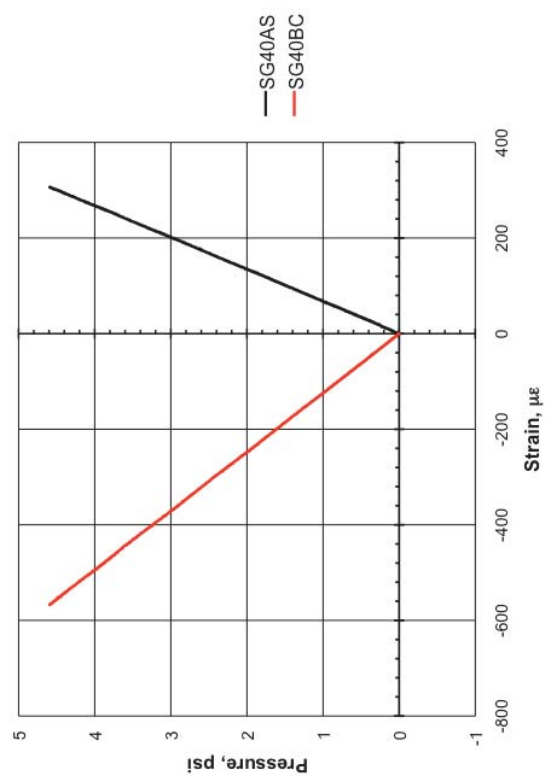


Figure B51. Checkout test 2, strain gages SG40AS and SG40BC.

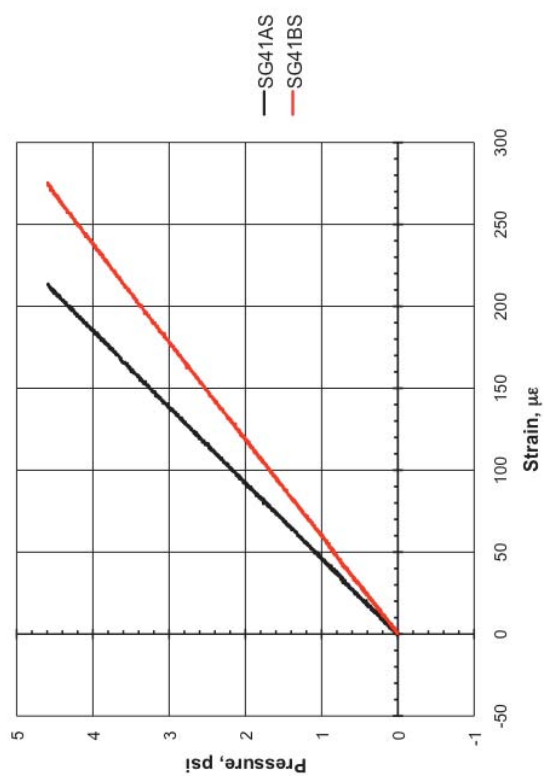


Figure B52. Checkout test 2, strain gages SG41AS and SG41BS.



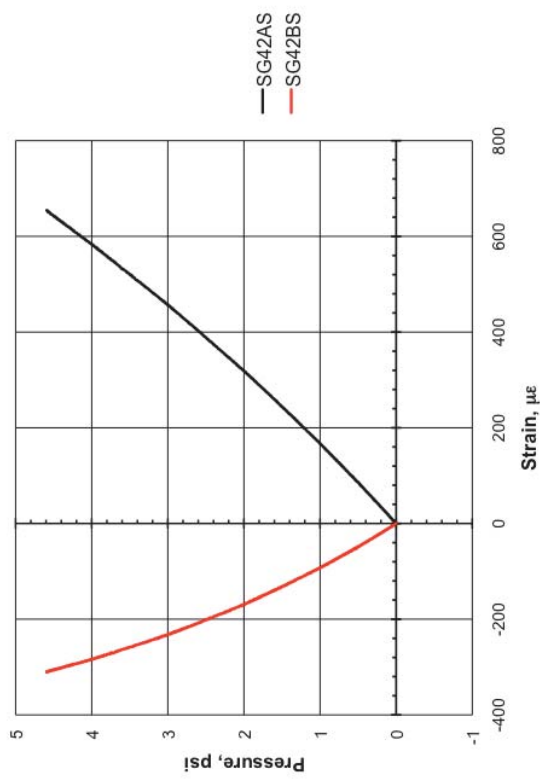


Figure B53. Checkout test 2, strain gages SG42AS and SG42BS.

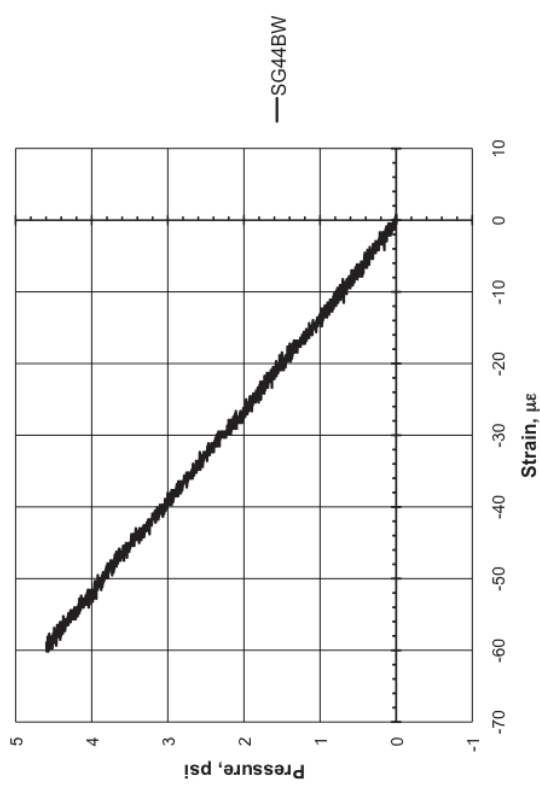


Figure B55. Checkout test 2, strain gage SG44BW.

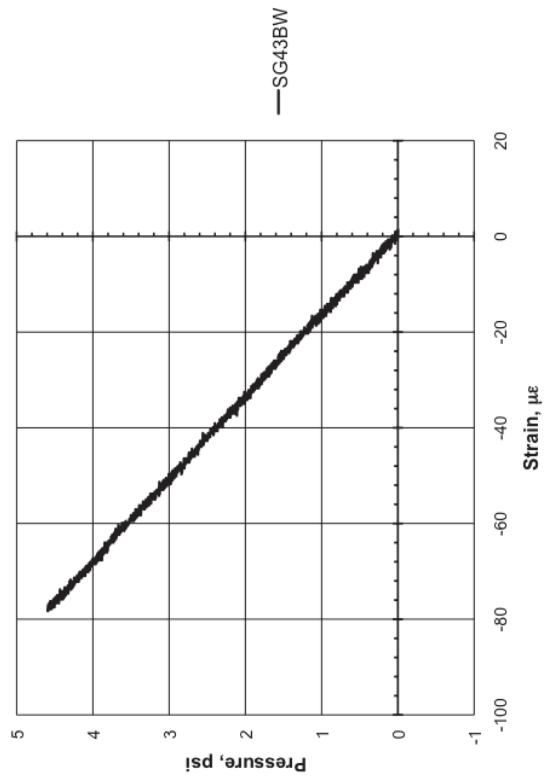


Figure B54. Checkout test 2, strain gage SG43BW.

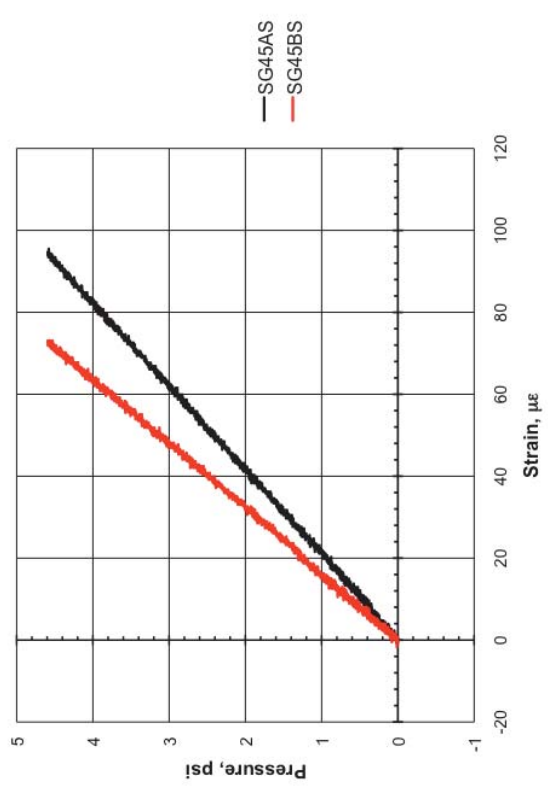


Figure B56. Checkout test 2, strain gages SG45AS and SG45BS.

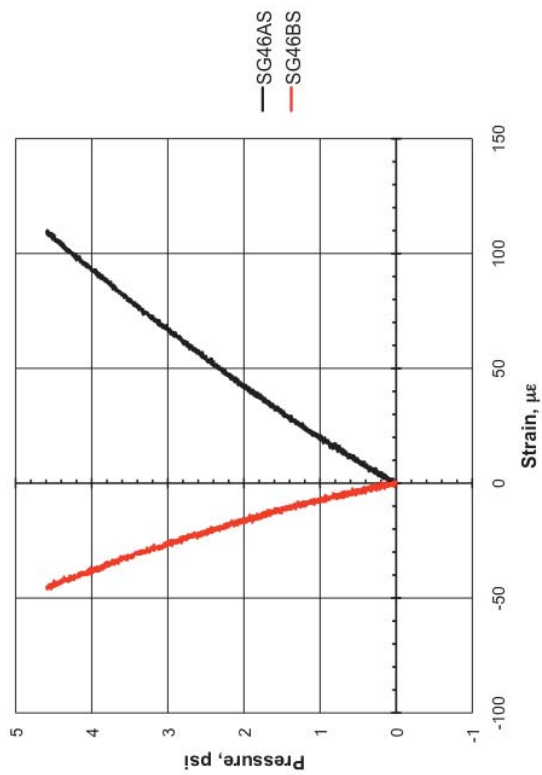


Figure B57. Checkout test 2, strain gages SG46AS and SG46BS.

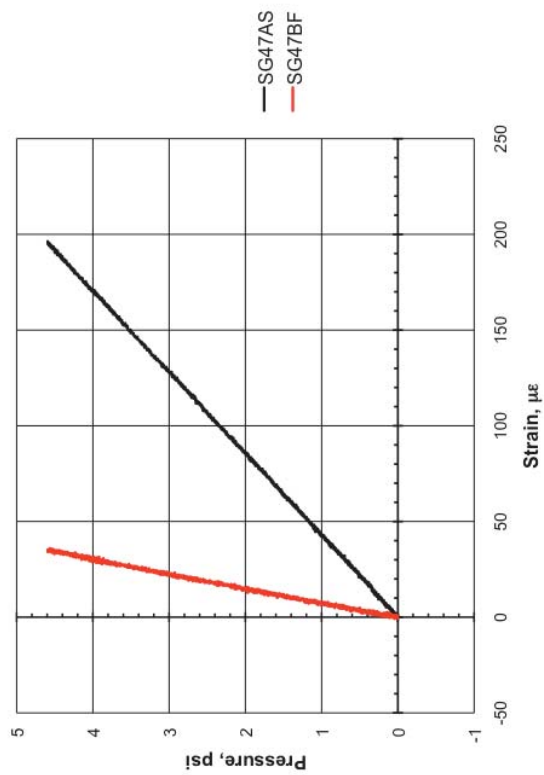


Figure B58. Checkout test 2, strain gages SG47AS and SG47BF.

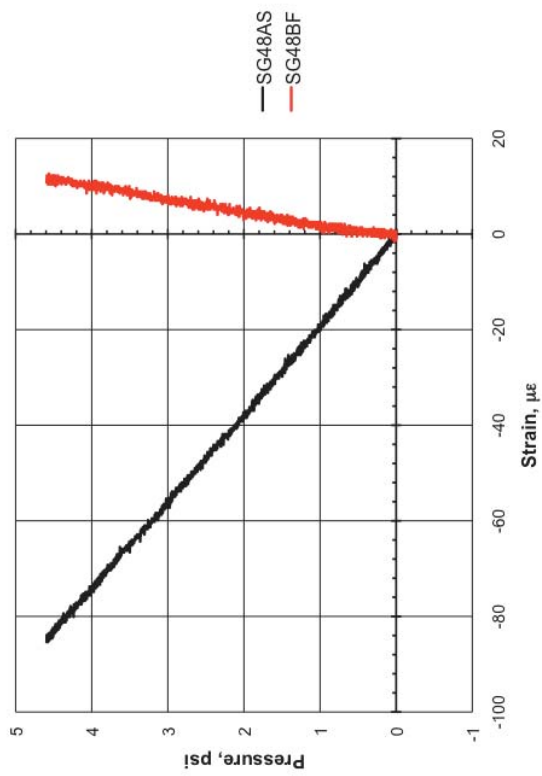


Figure B59. Checkout test 2, strain gages SG48AS and SG48BF.

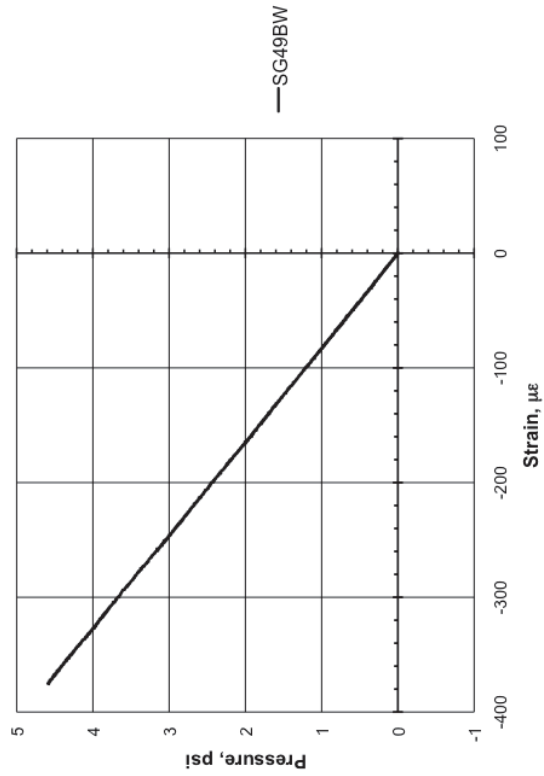


Figure B60. Checkout test 2, strain gage SG49BW.

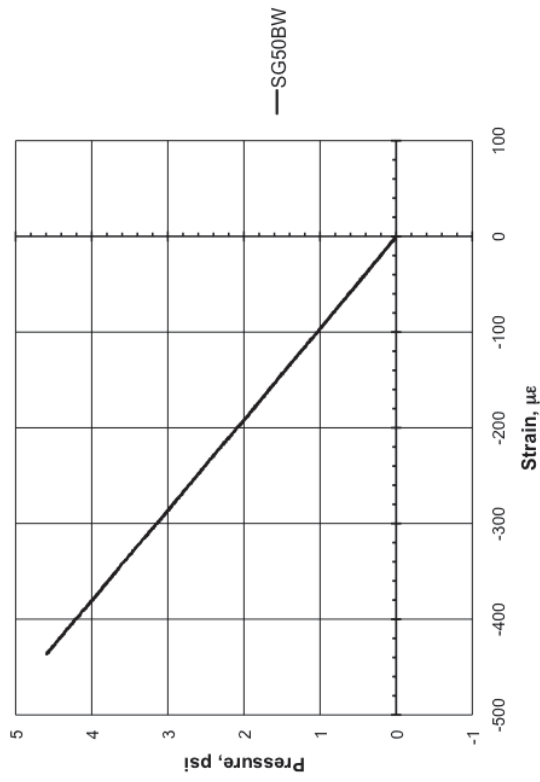


Figure B61. Checkout test 2, strain gage SG50BW.

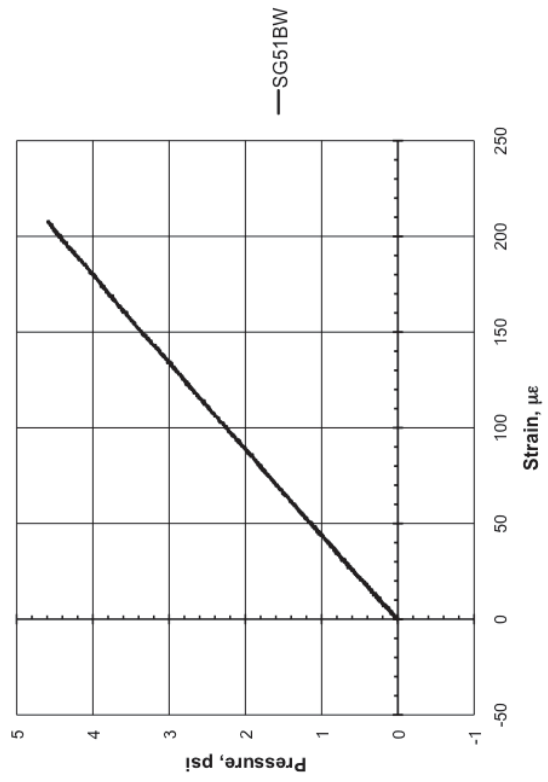


Figure B62. Checkout test 2, strain gage SG51BW.

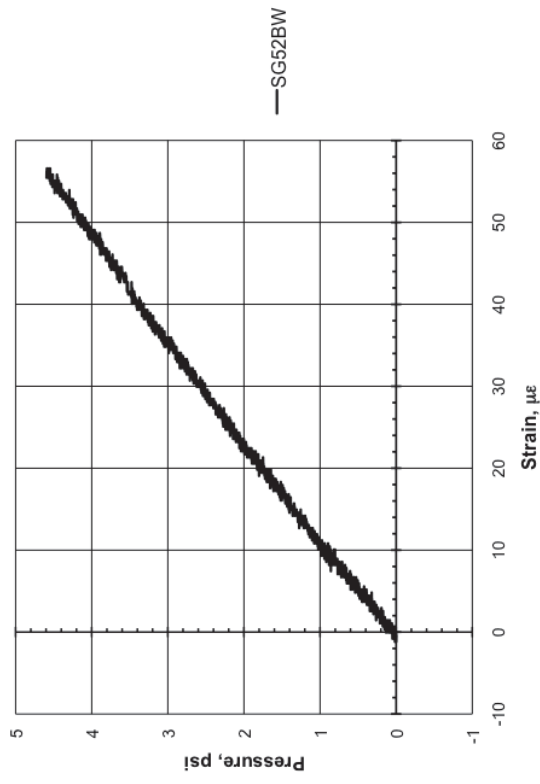


Figure B63. Checkout test 2, strain gage SG52BW.

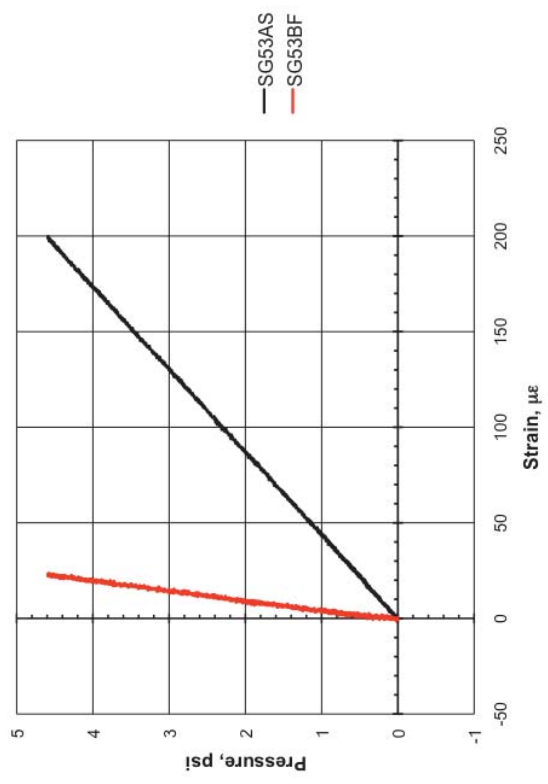


Figure B64. Checkout test 2, strain gages SG53AS and SG53BF.

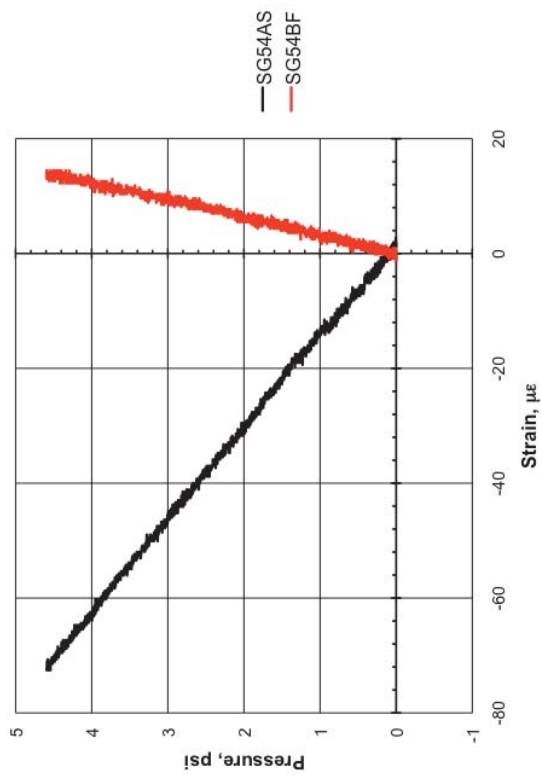


Figure B65. Checkout test 2, strain gages SG54AS and SG54BF.

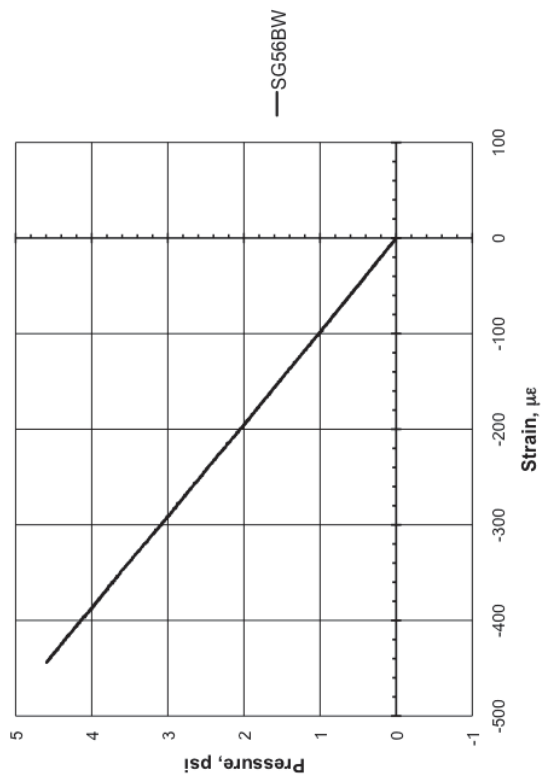


Figure B67. Checkout test 2, strain gage SG56BW.

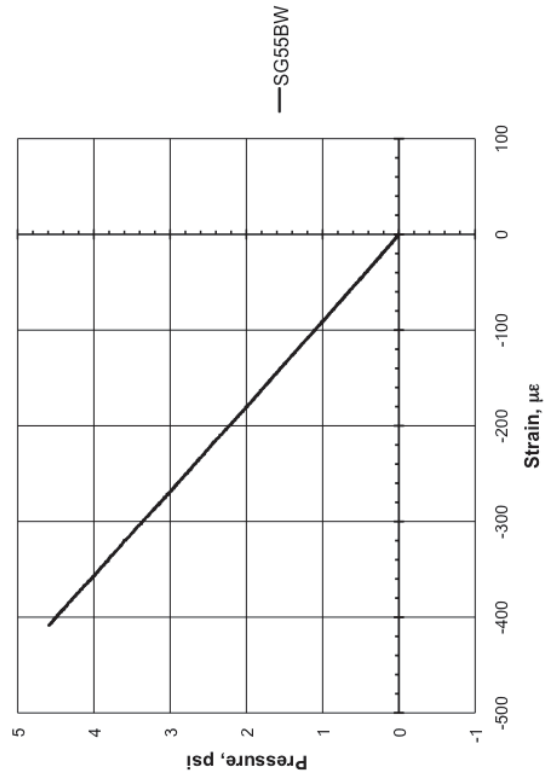


Figure B66. Checkout test 2, strain gage SG55BW.

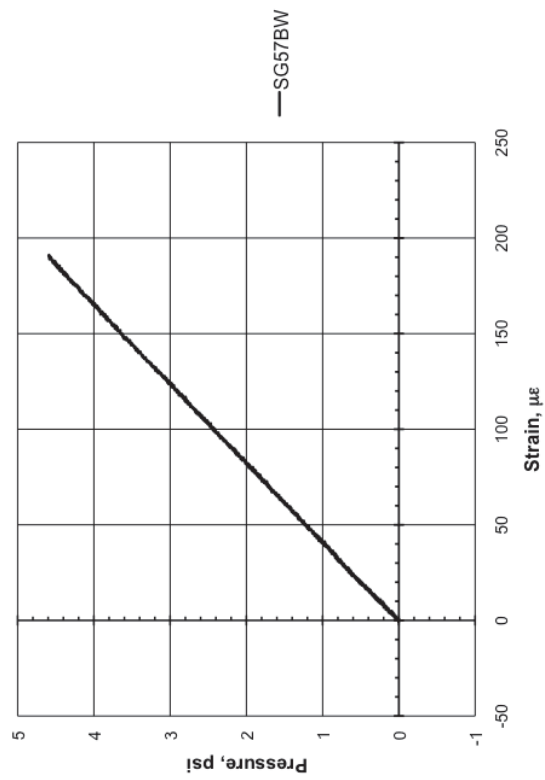


Figure B68. Checkout test 2, strain gage SG57BW.

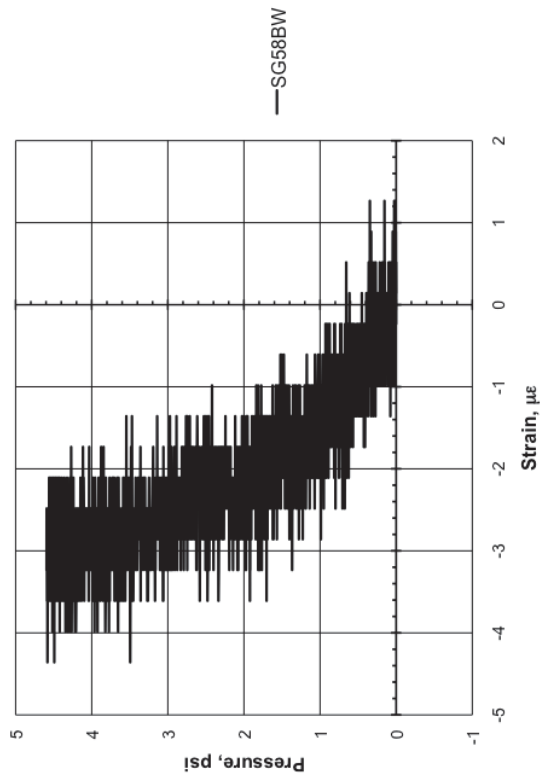


Figure B69. Checkout test 2, strain gage SG58BW.

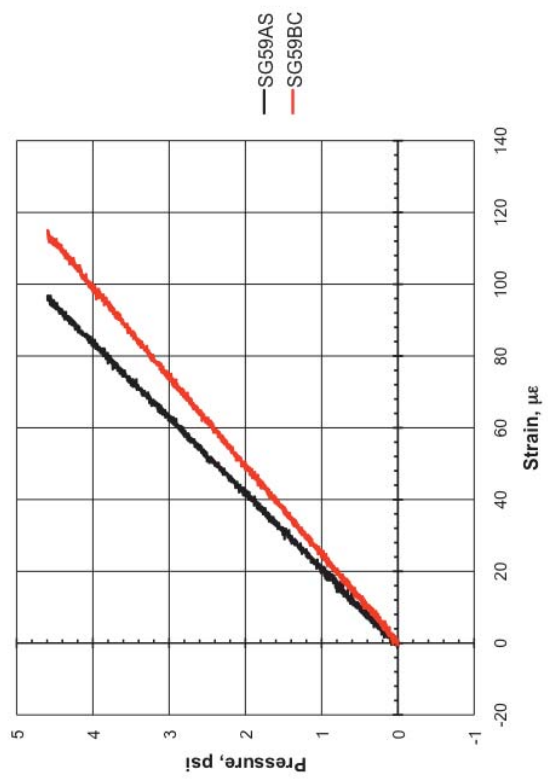


Figure B70. Checkout test 2, strain gages SG59AS and SG59BC.

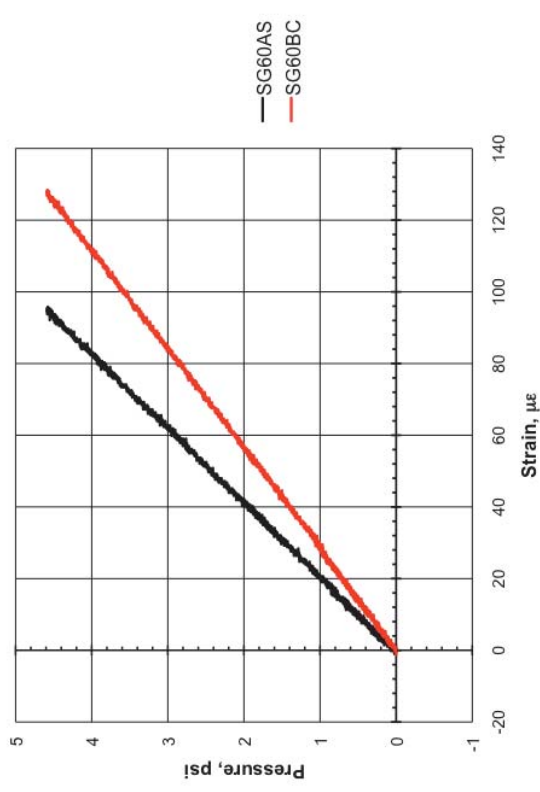


Figure B71. Checkout test 2, strain gages SG60AS and SG60BC.

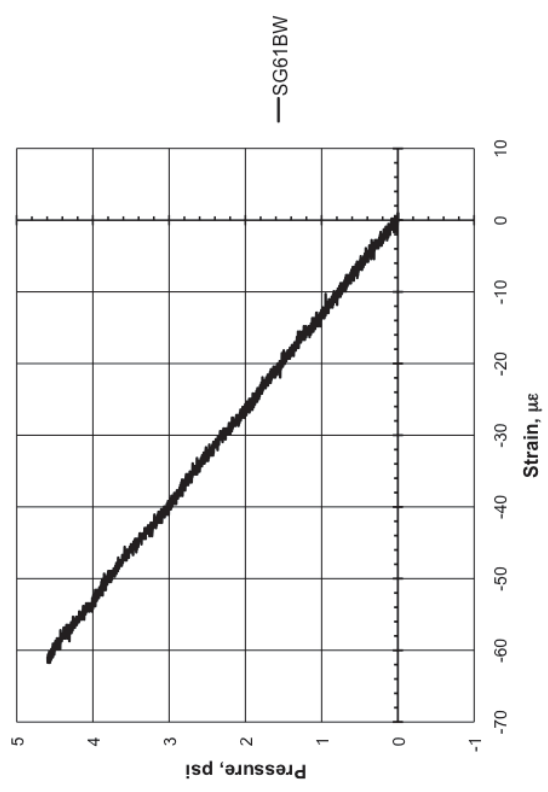


Figure B72. Checkout test 2, strain gage SG61BW.

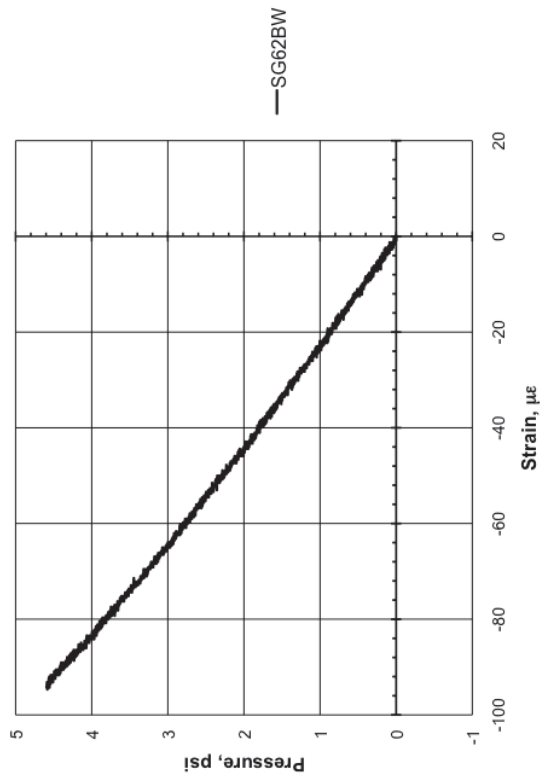


Figure B73. Checkout test 2, strain gage SG62BW.

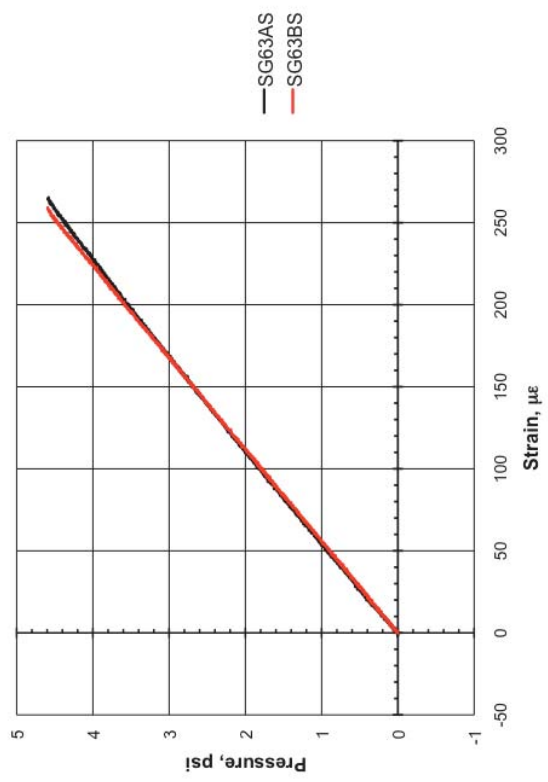


Figure B74. Checkout test 2, strain gages SG63AS and SG63BS.

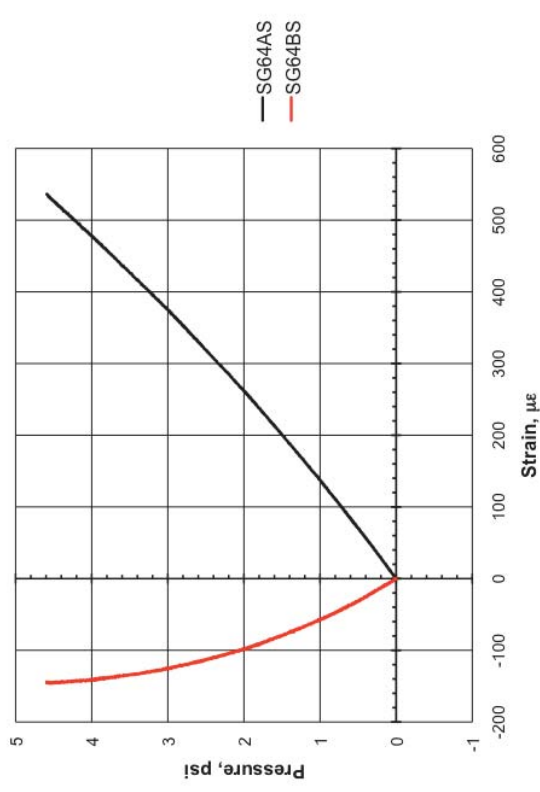


Figure B75. Checkout test 2, strain gages SG64AS and SG64BS.

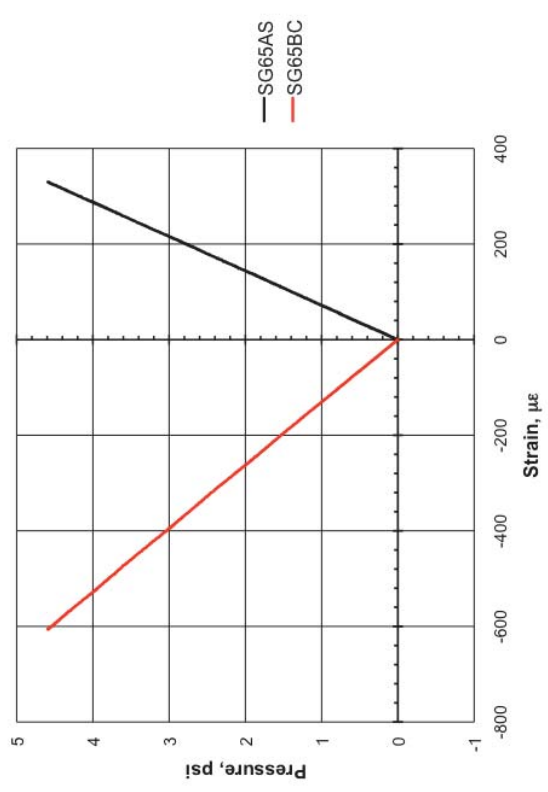


Figure B76. Checkout test 2, strain gages SG65AS and SG65BC.

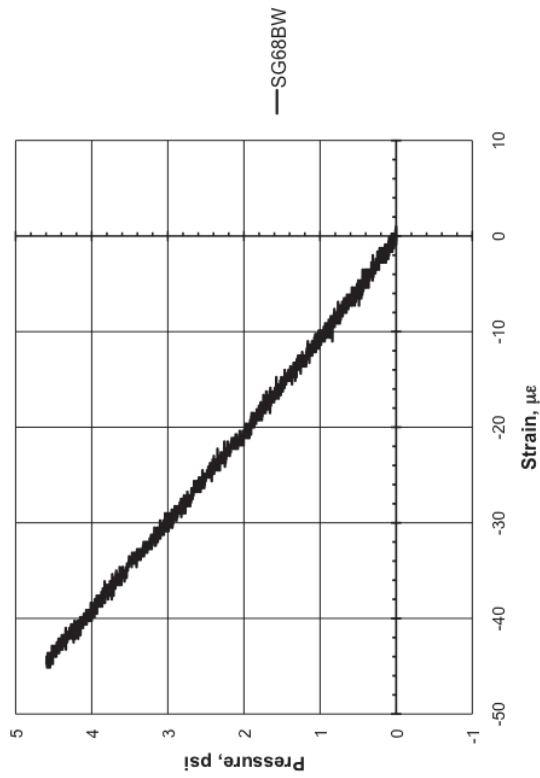


Figure B79. Checkout test 2, strain gage SG68BW.

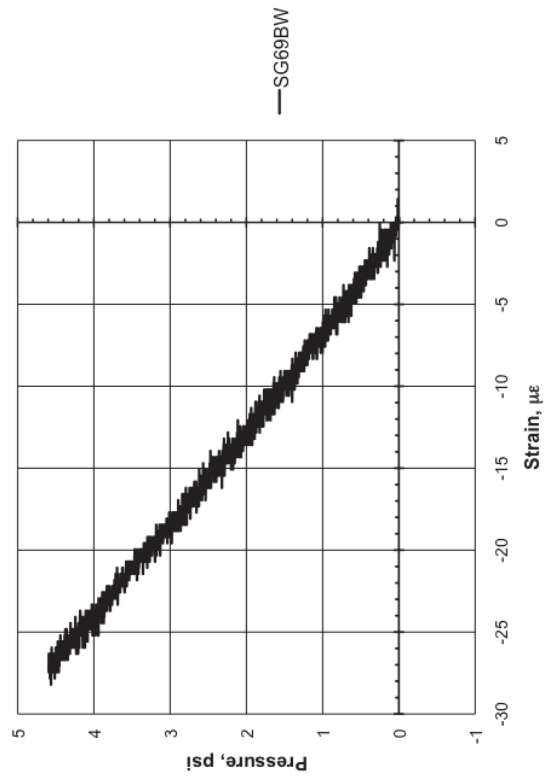


Figure B80. Checkout test 2, strain gage SG69BW.

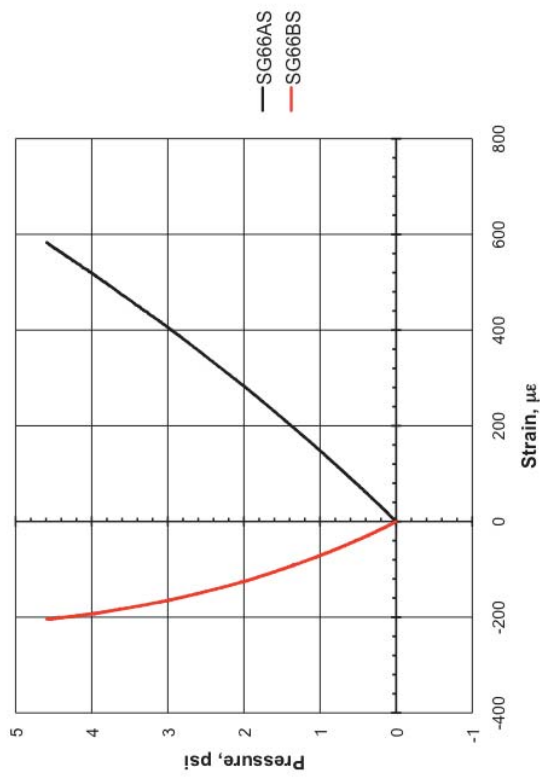


Figure B77. Checkout test 2, strain gages SG66AS and SG66BS.

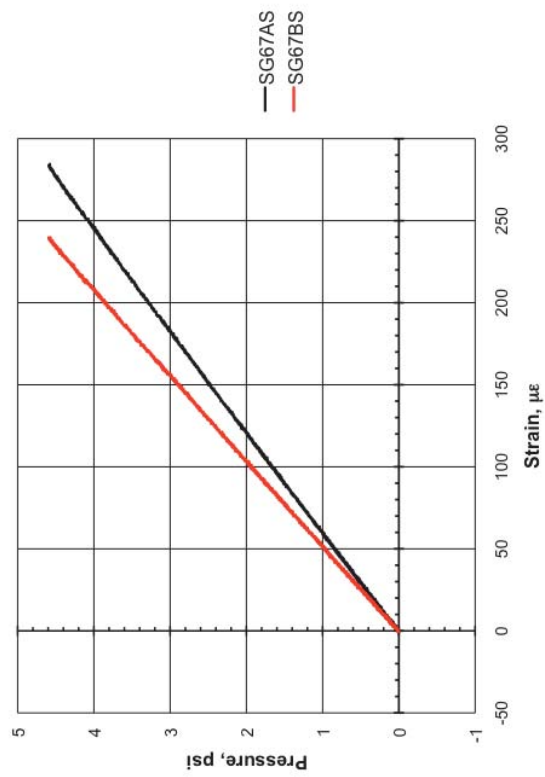


Figure B78. Checkout test 2, strain gages SG67AS and SG67BS.



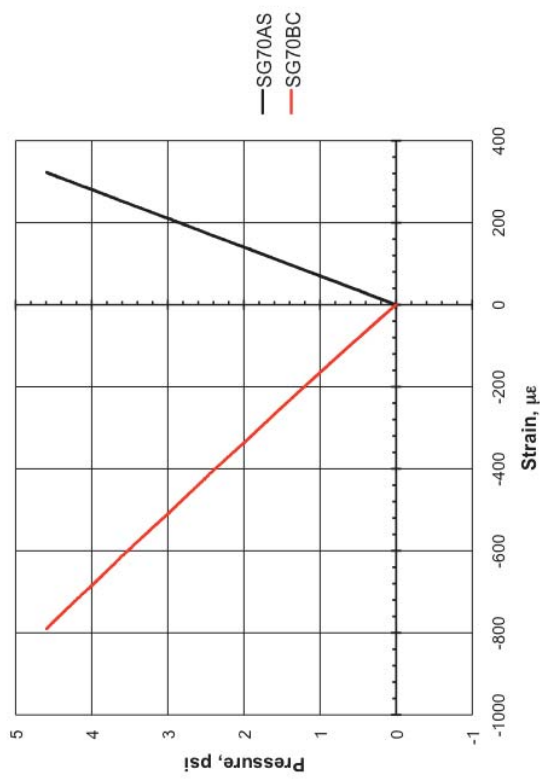


Figure B81. Checkout test 2, strain gages SG70AS and SG70BC.

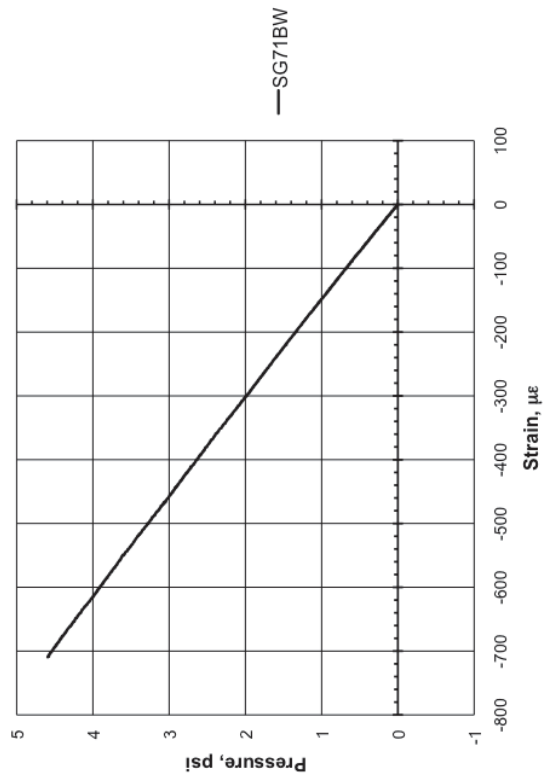


Figure B82. Checkout test 2, strain gage SG71BW.

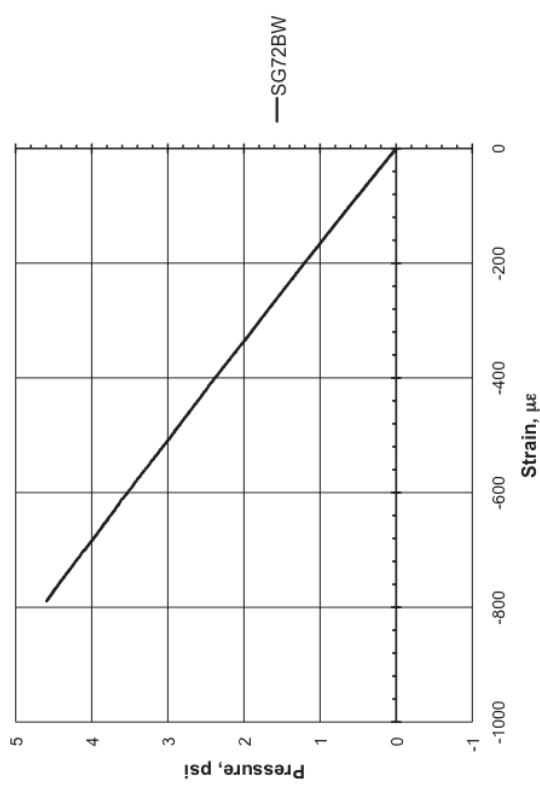


Figure B83. Checkout test 2, strain gage SG72BW.

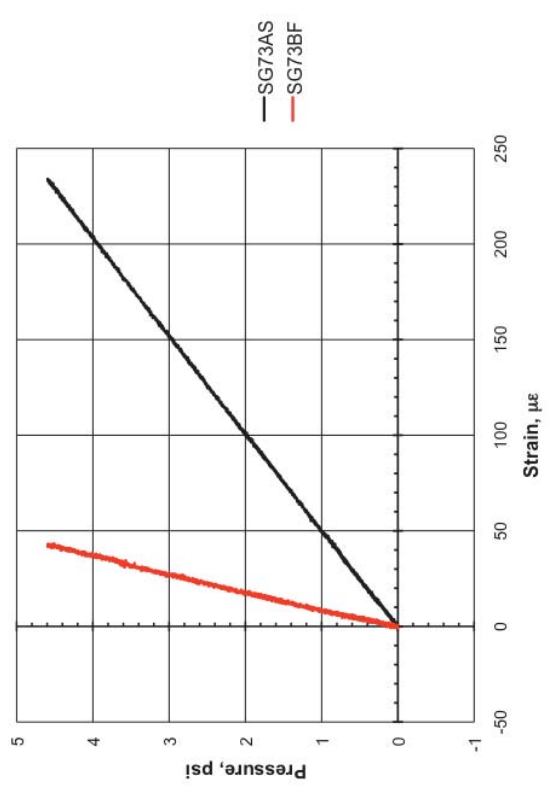


Figure B84. Checkout test 2, strain gages SG73AS and SG73BF.

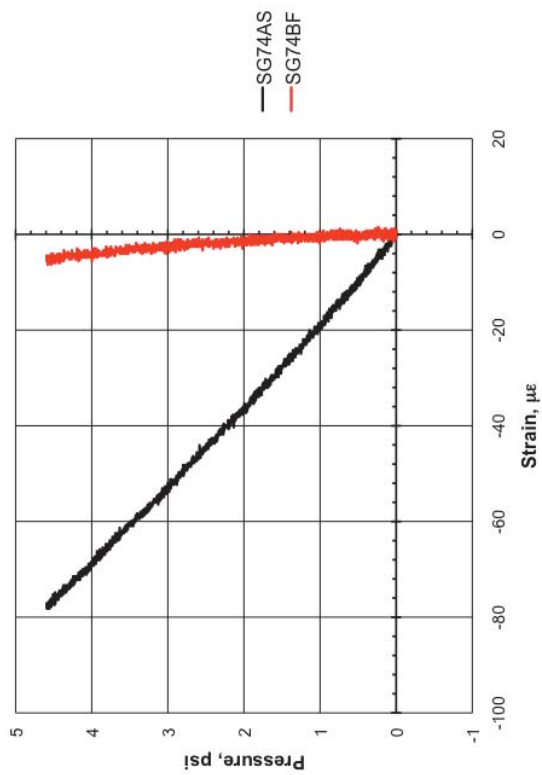


Figure B85. Checkout test 2, strain gages SG74AS and SG74BF.

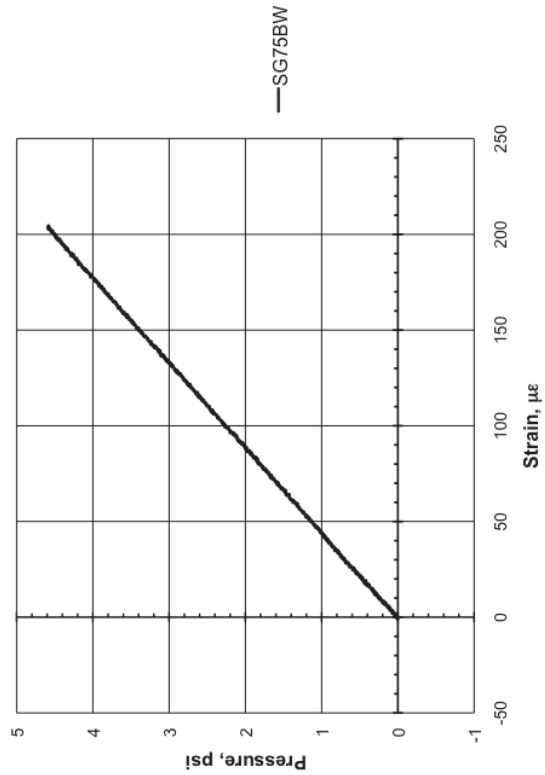


Figure B86. Checkout test 2, strain gage SG75BW.

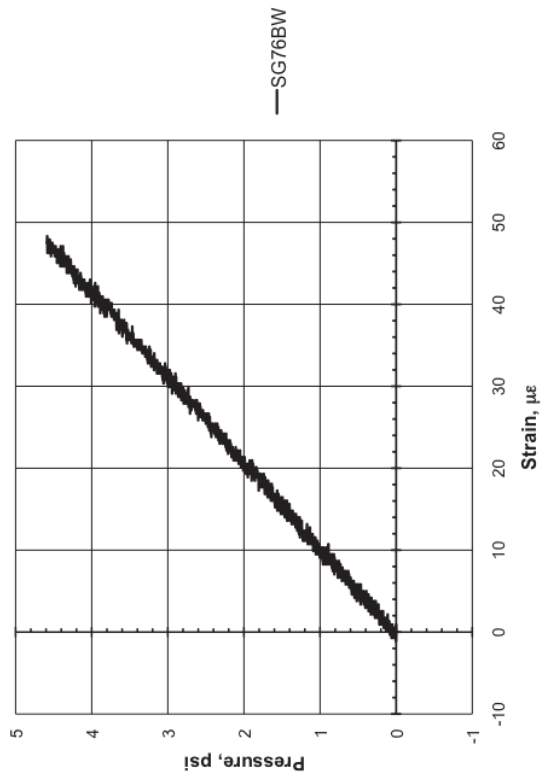


Figure B87. Checkout test 2, strain gage SG76BW.

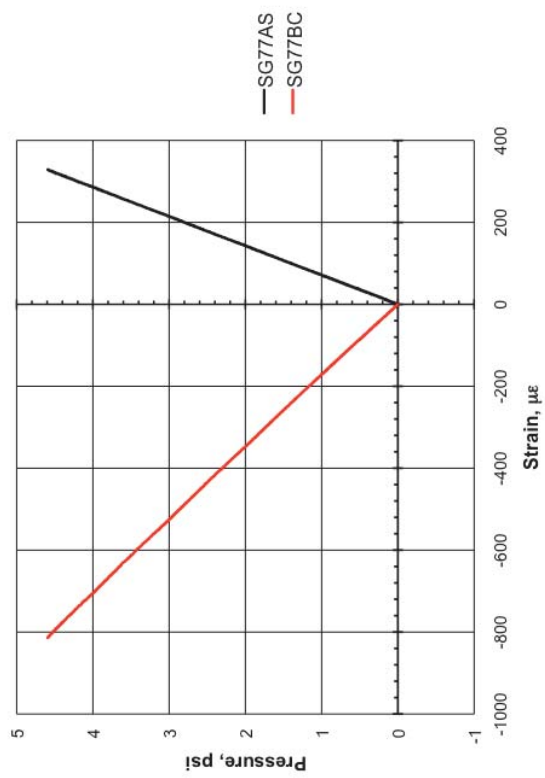


Figure B88. Checkout test 2, strain gages SG77AS and SG77BC.

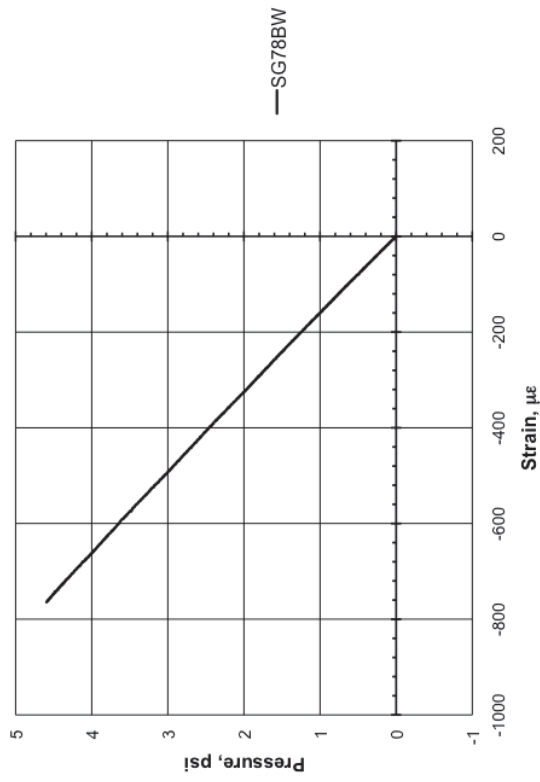


Figure B89. Checkout test 2, strain gage SG78BW.

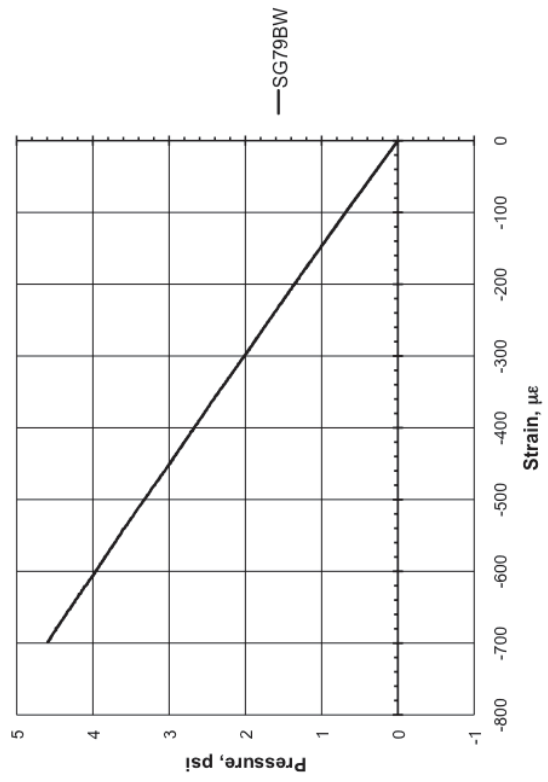


Figure B90. Checkout test 2, strain gage SG79BW.

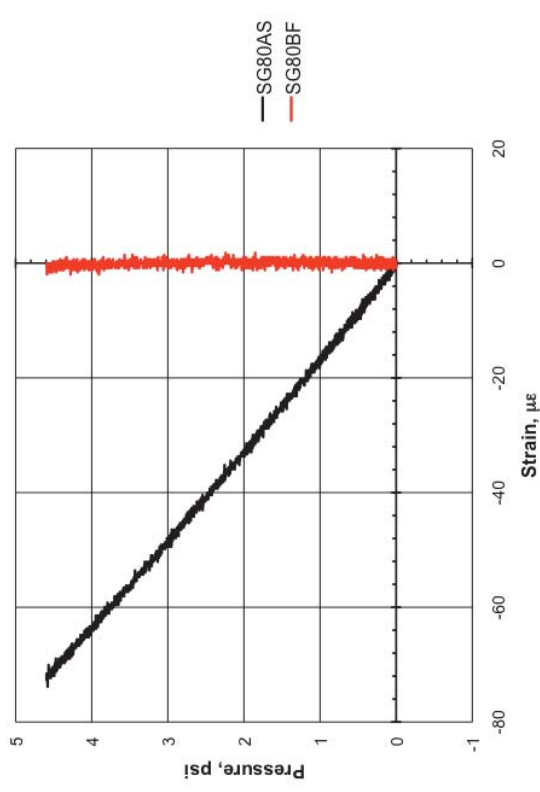


Figure B91. Checkout test 2, strain gages SG80AS and SG80BF.

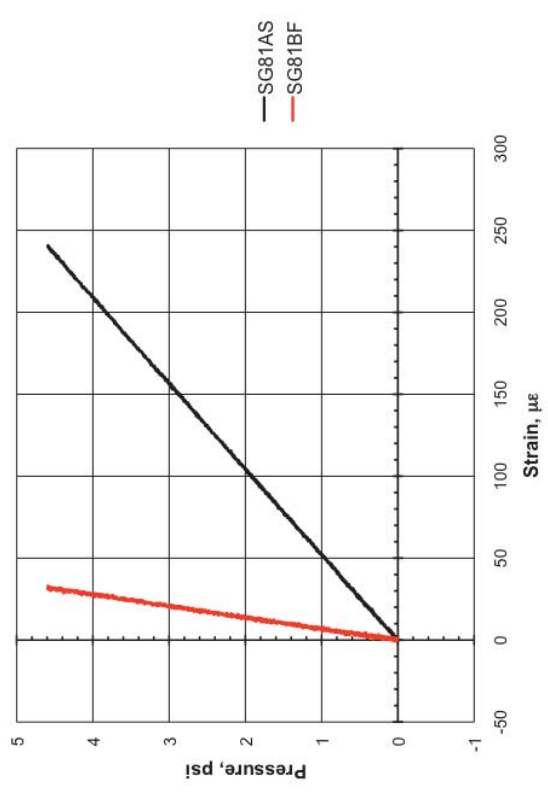


Figure B92. Checkout test 2, strain gages SG81AS and SG81BF.

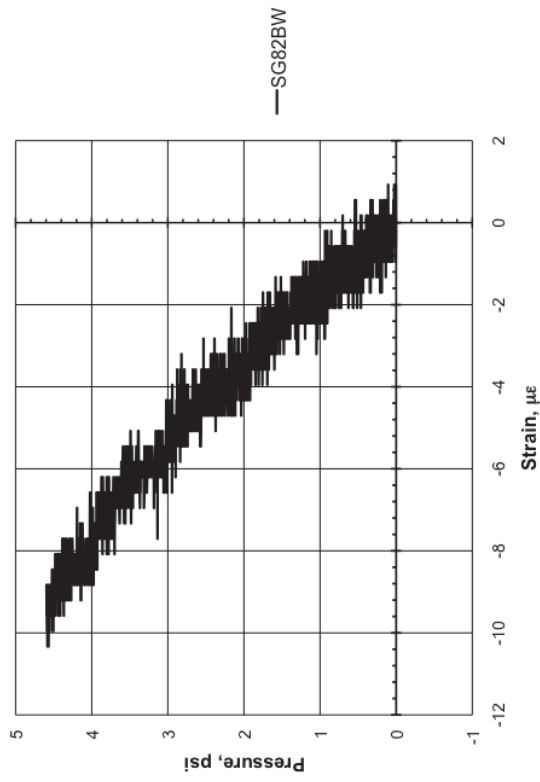


Figure B93. Checkout test 2, strain gage SG82BW.

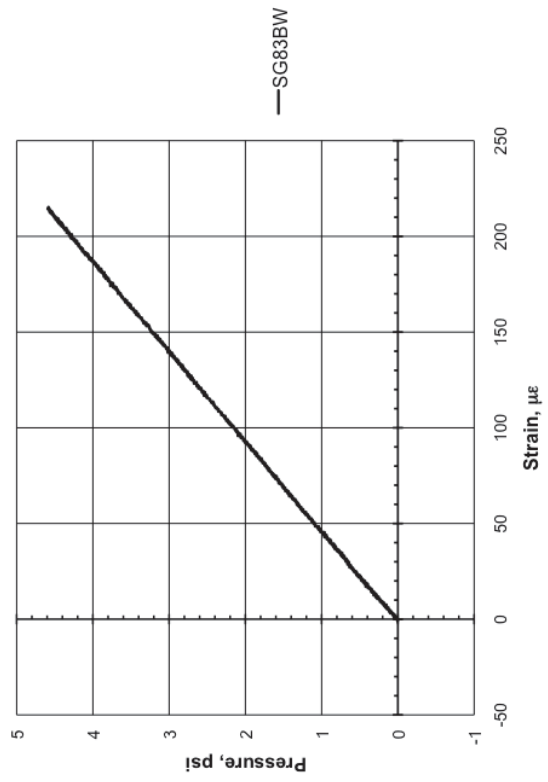


Figure B94. Checkout test 2, strain gage SG83BW.

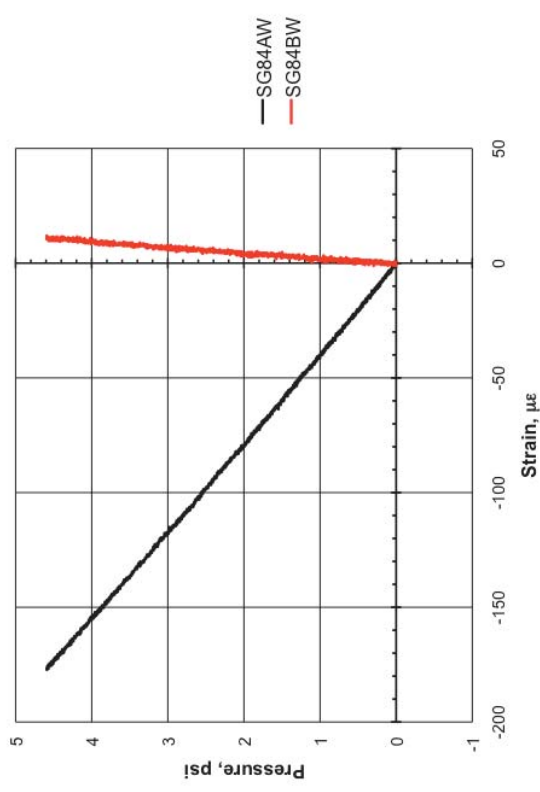


Figure B95. Checkout test 2, strain gages SG84AW and SG84BW.

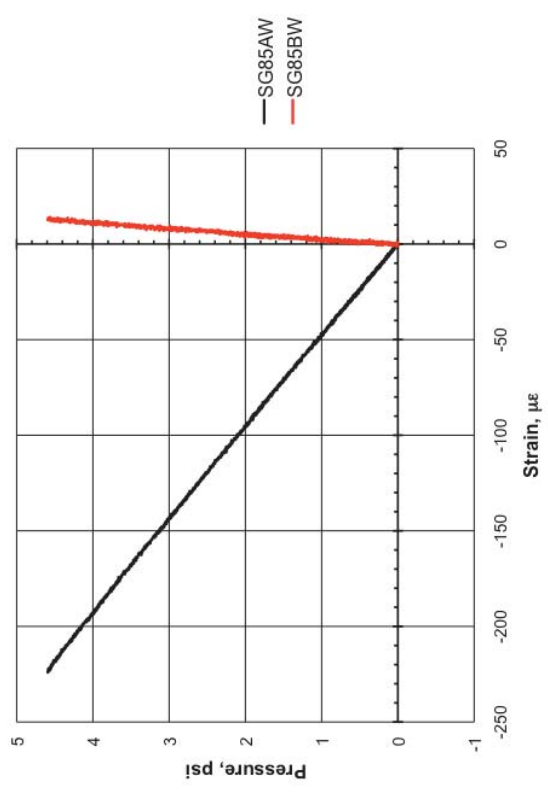


Figure B96. Checkout test 2, strain gages SG85AW and SG85BW.

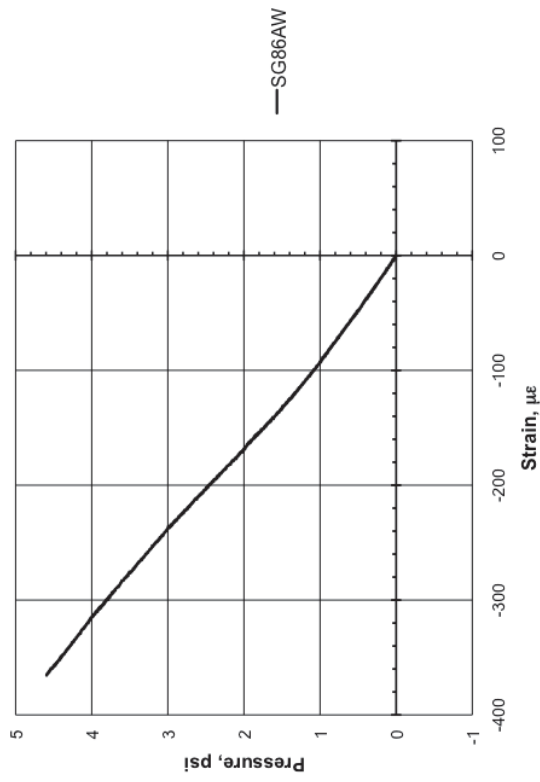


Figure B97. Checkout test 2, strain gage SG86AW.

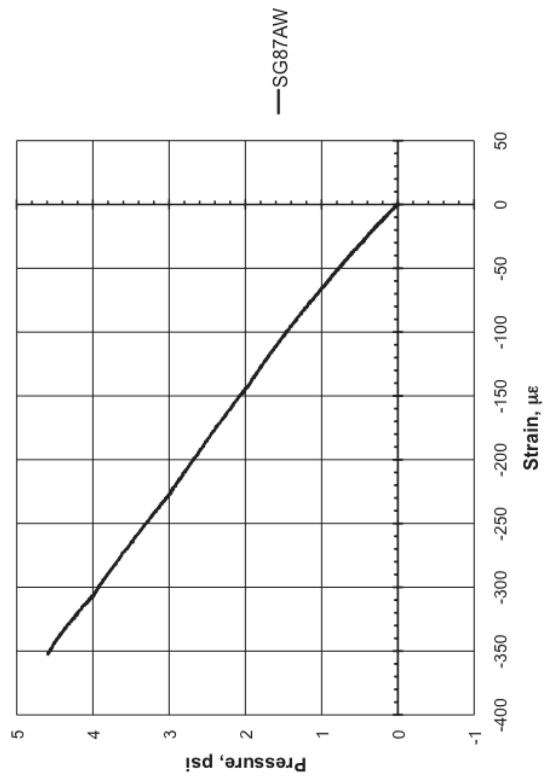


Figure B98. Checkout test 2, strain gage SG87AW.

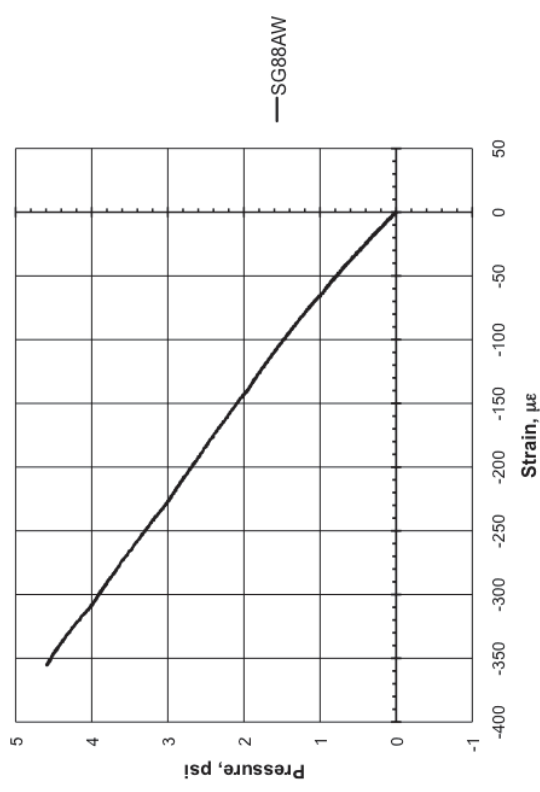


Figure B99. Checkout test 2, strain gage SG88AW.

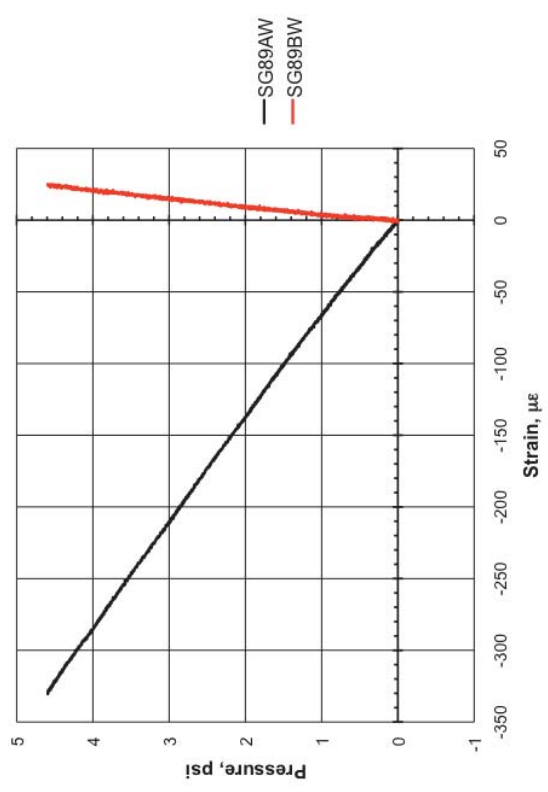


Figure B100. Checkout test 2, strain gages SG89AW and SG89BW.

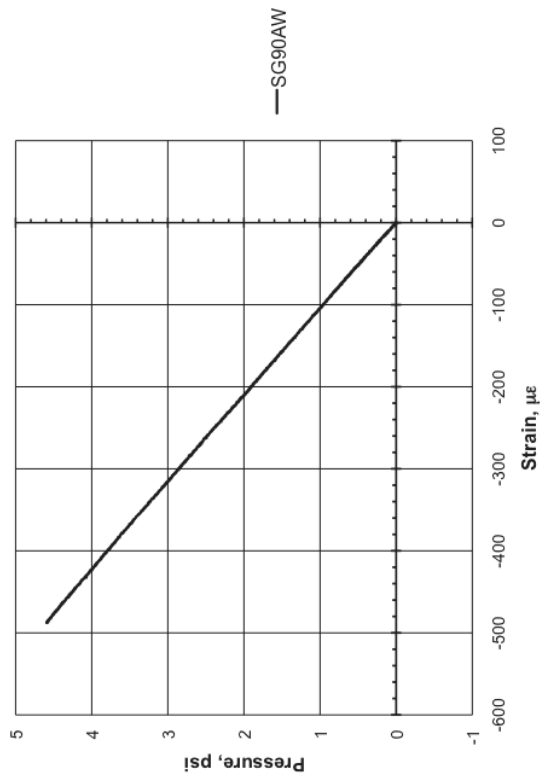


Figure B101. Checkout test 2, strain gage SG90AW.

B27

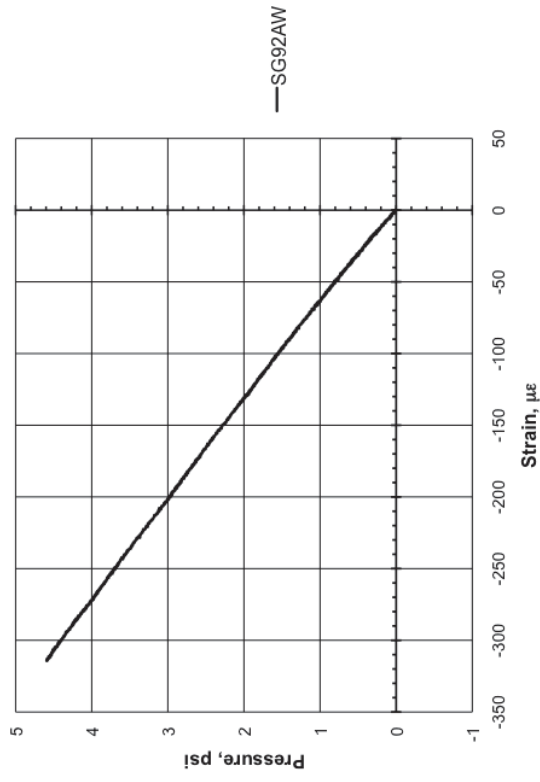


Figure B103. Checkout test 2, strain gage SG92AW.

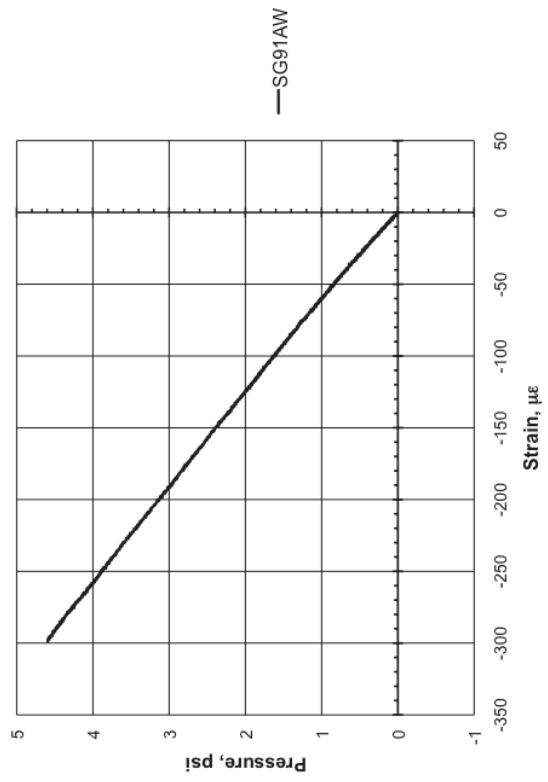


Figure B102. Checkout test 2, strain gage SG91AW.

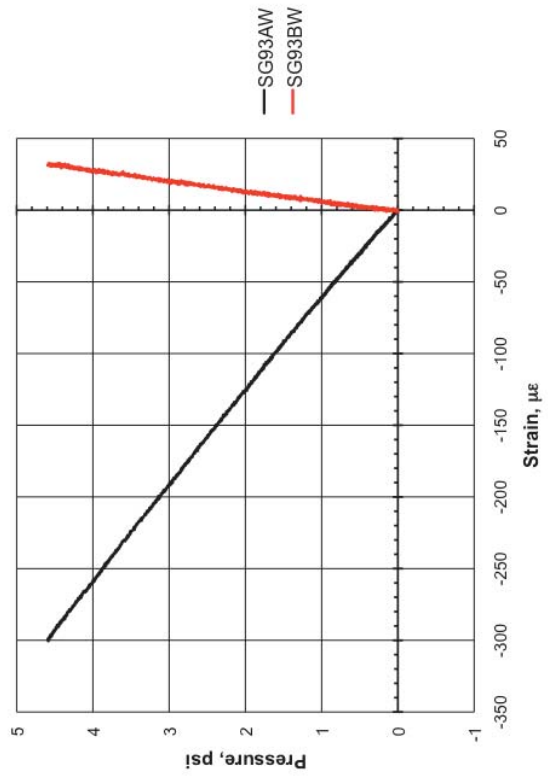


Figure B104. Checkout test 2, strain gages SG93AW and SG93BW.

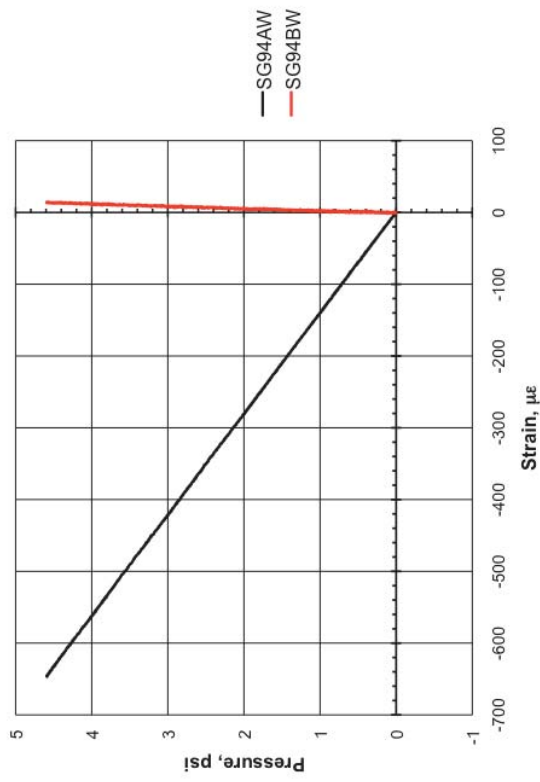


Figure B105. Checkout test 2, strain gages SG94AW and SG94BW.

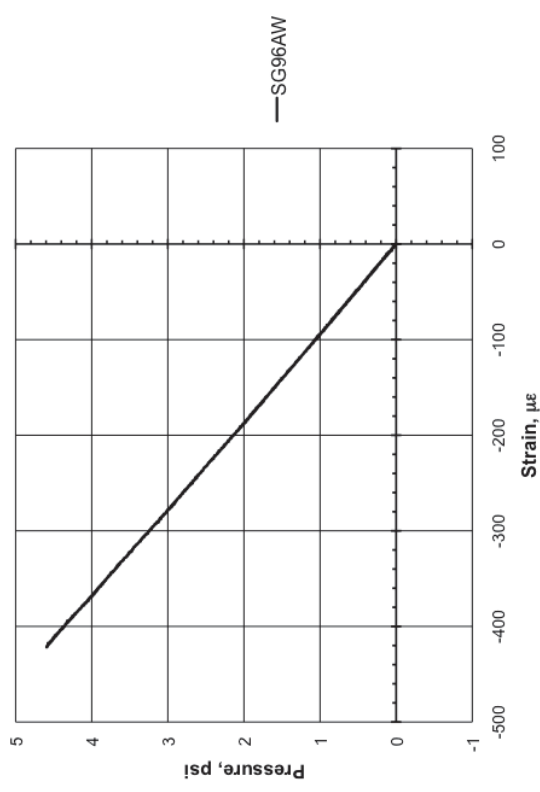


Figure B107. Checkout test 2, strain gage SG96AW.

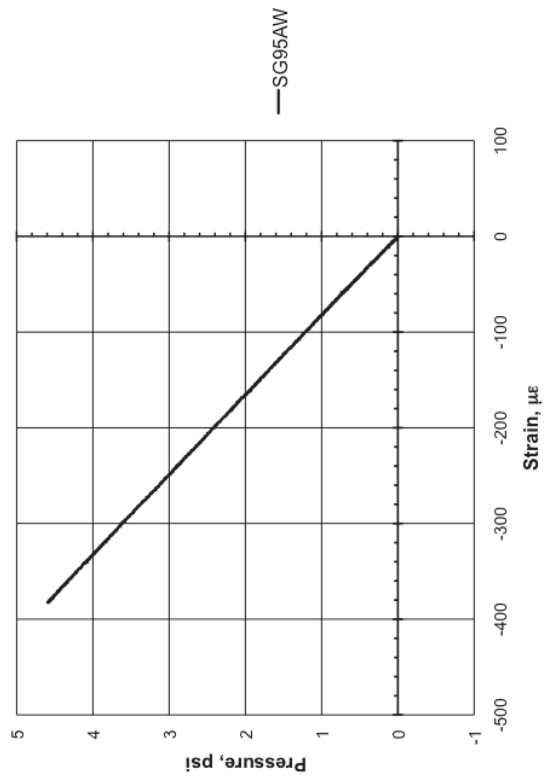


Figure B106. Checkout test 2, strain gage SG95AW.

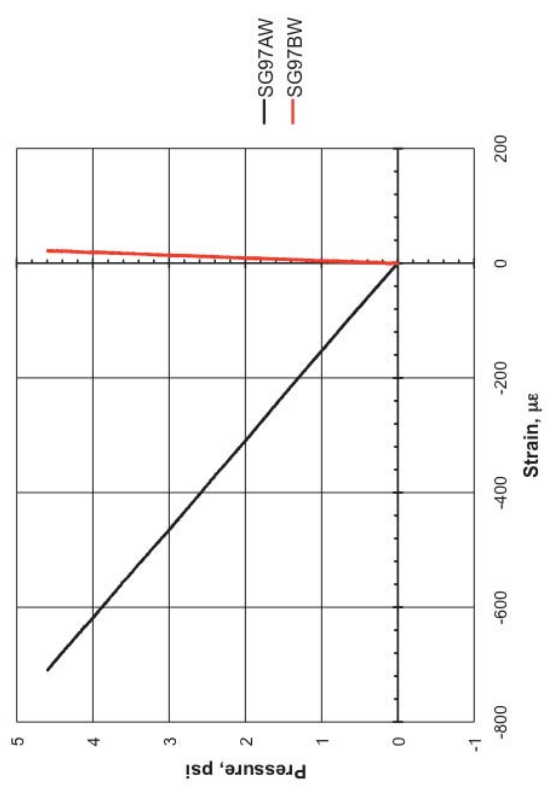


Figure B108. Checkout test 2, strain gages SG97AW and SG97BW.

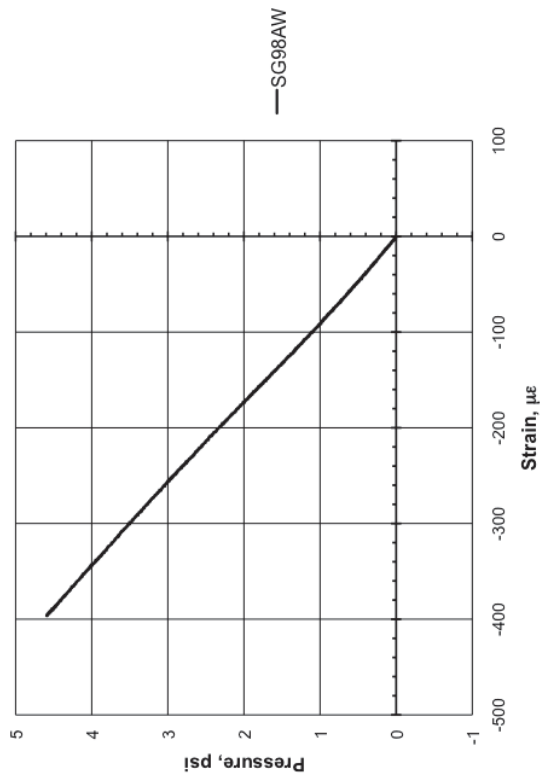


Figure B109. Checkout test 2, strain gage SG98AW.

B29

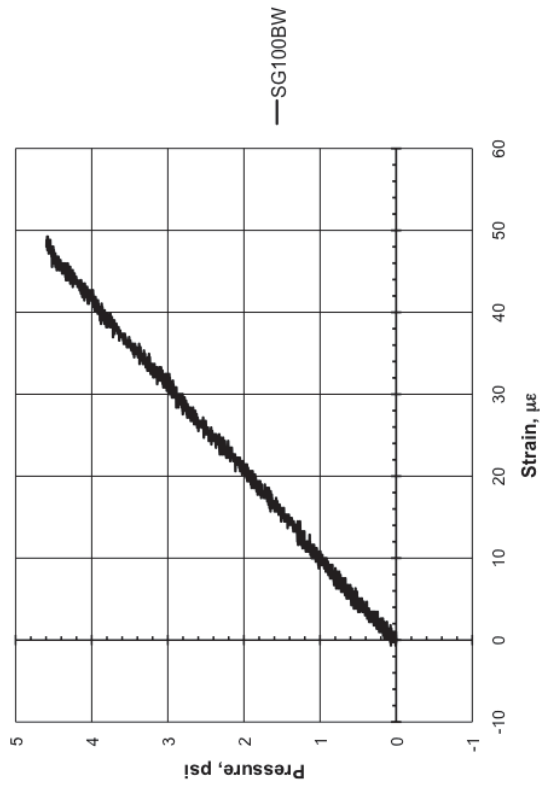


Figure B111. Checkout test 2, strain gage SG100BW.

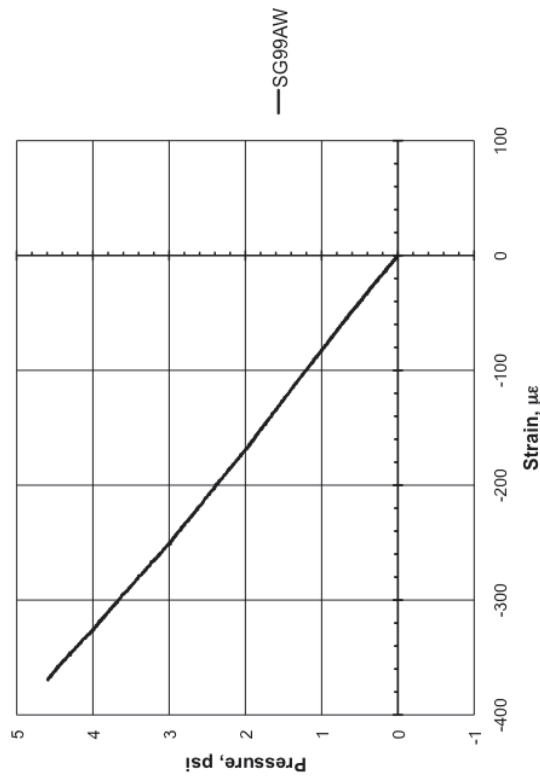


Figure B110. Checkout test 2, strain gage SG99AW.

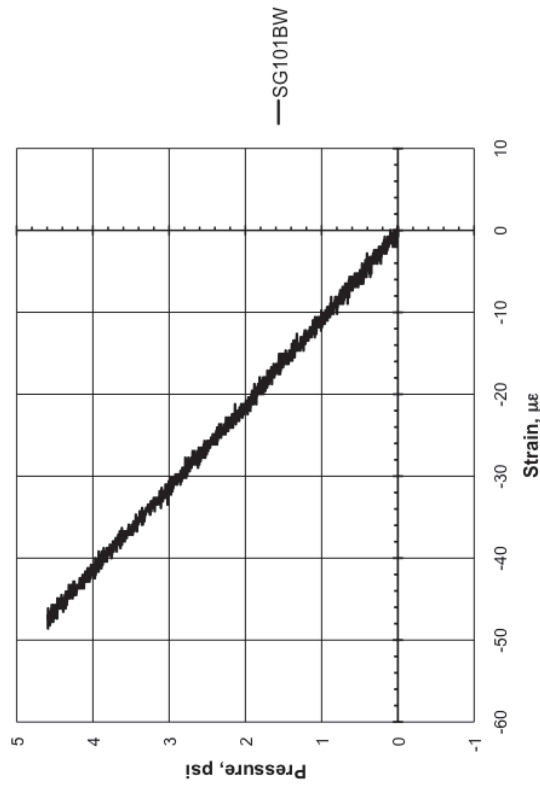


Figure B112. Checkout test 2, strain gage SG101BW.



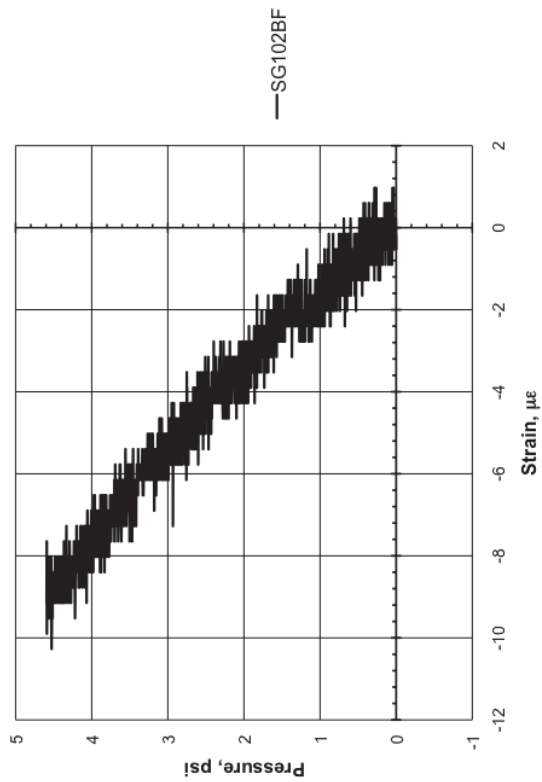


Figure B113. Checkout test 2, strain gage SG102BF.

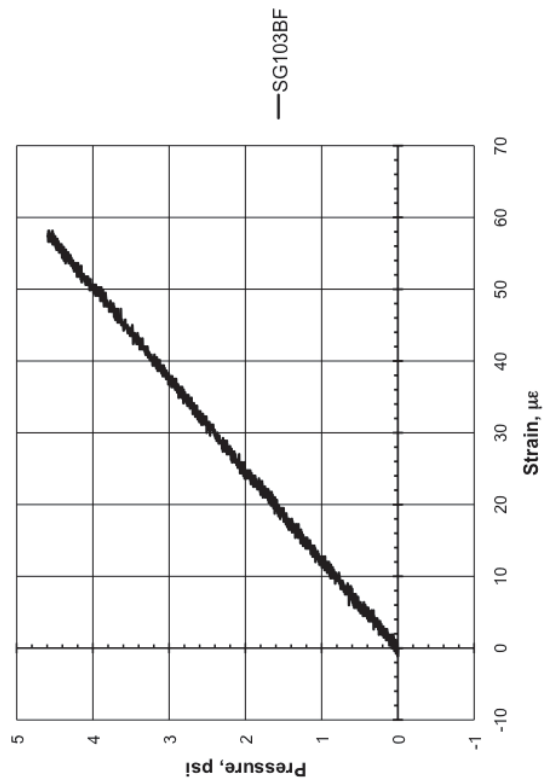


Figure B114. Checkout test 2, strain gage SG103BF.

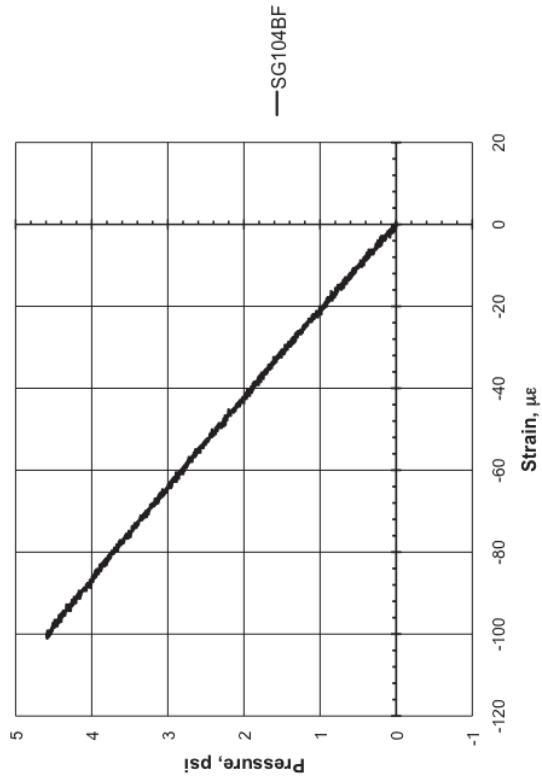


Figure B115. Checkout test 2, strain gage SG104BF.

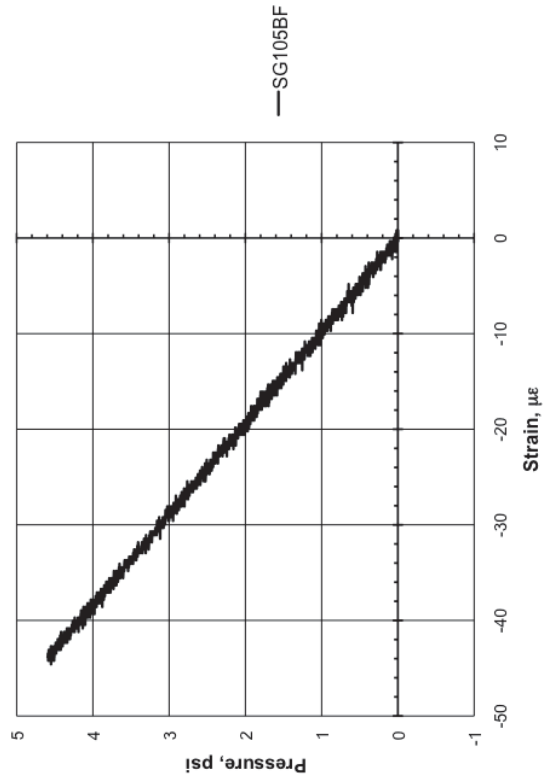


Figure B116. Checkout test 2, strain gage SG105BF.

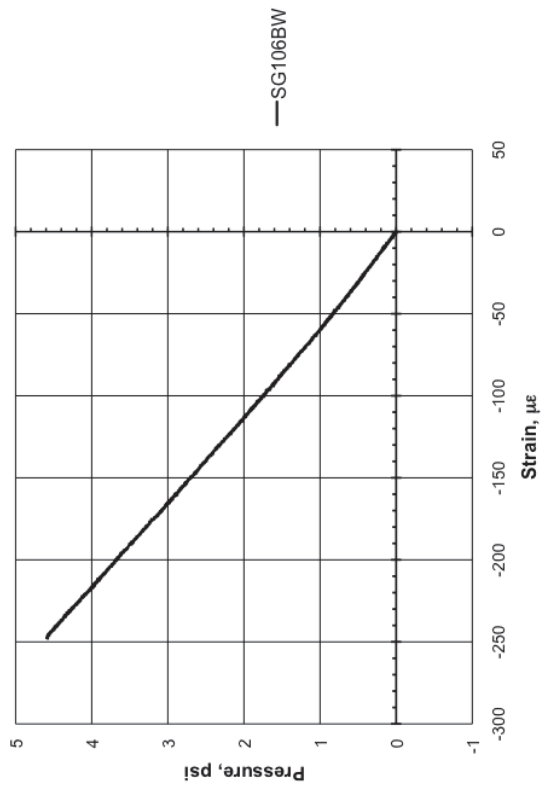


Figure B117. Checkout test 2, strain gage SG106BW.

B31

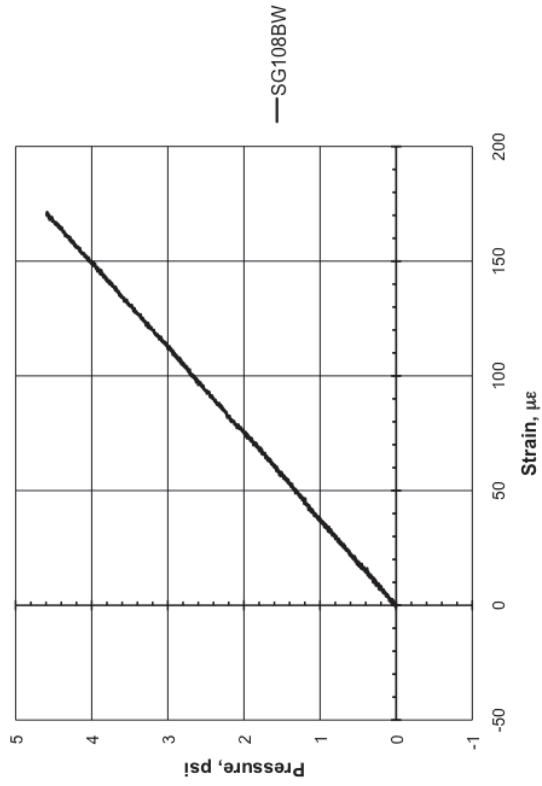


Figure B119. Checkout test 2, strain gage SG108BW.

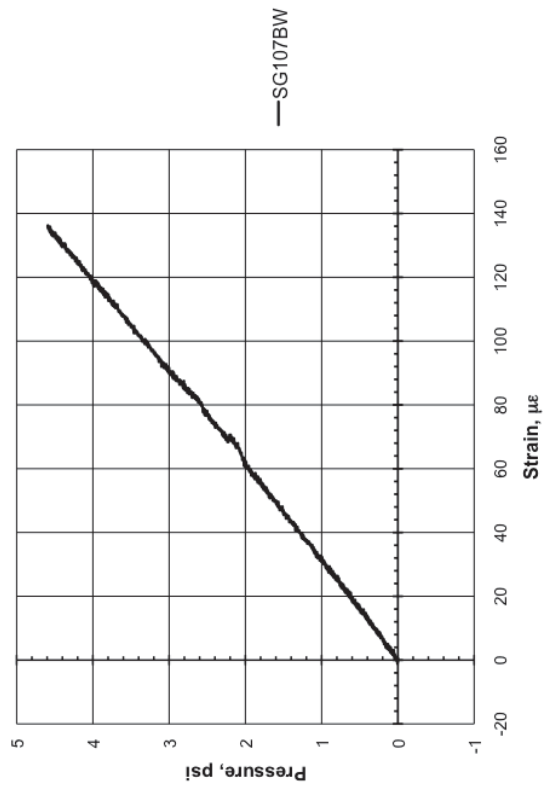


Figure B118. Checkout test 2, strain gage SG107BW.

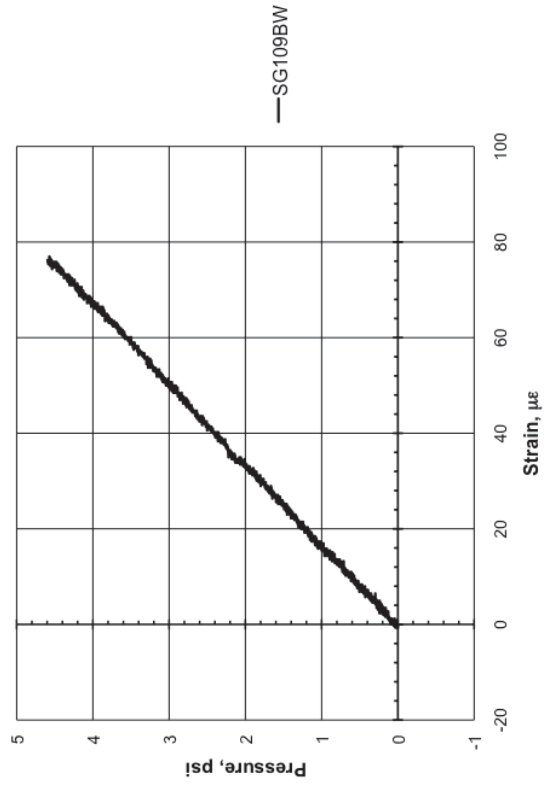


Figure B120. Checkout test 2, strain gage SG109BW.

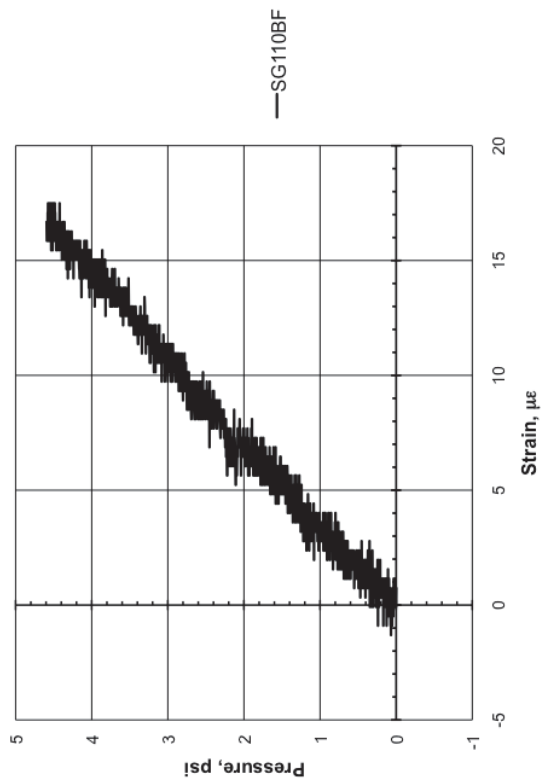


Figure B121. Checkout test 2, strain gage SG110BF.

B32

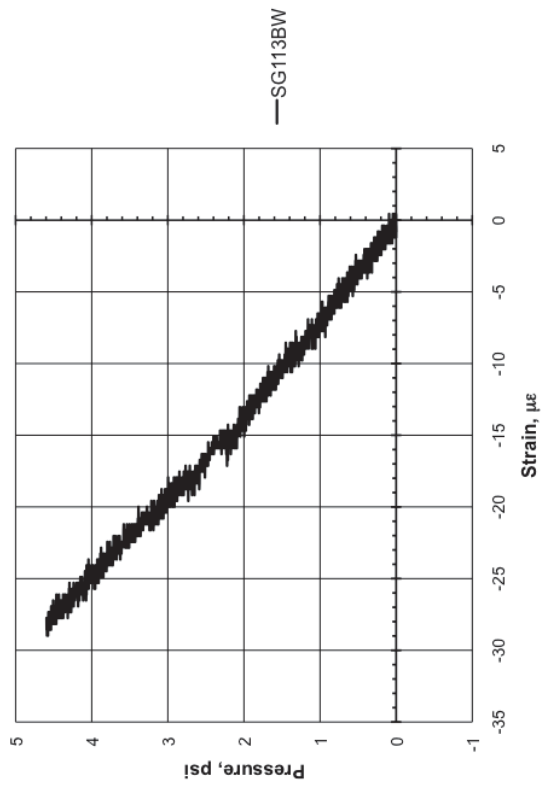


Figure B123. Checkout test 2, strain gage SG113BW.

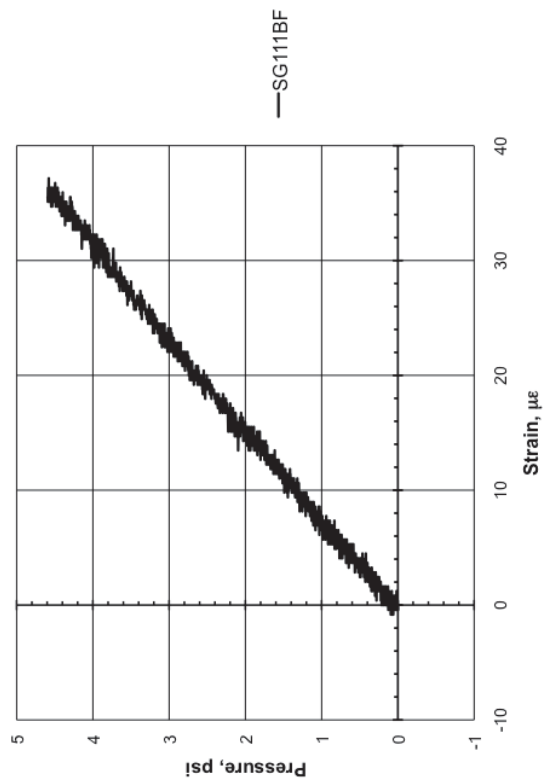


Figure B122. Checkout test 2, strain gage SG111BF.

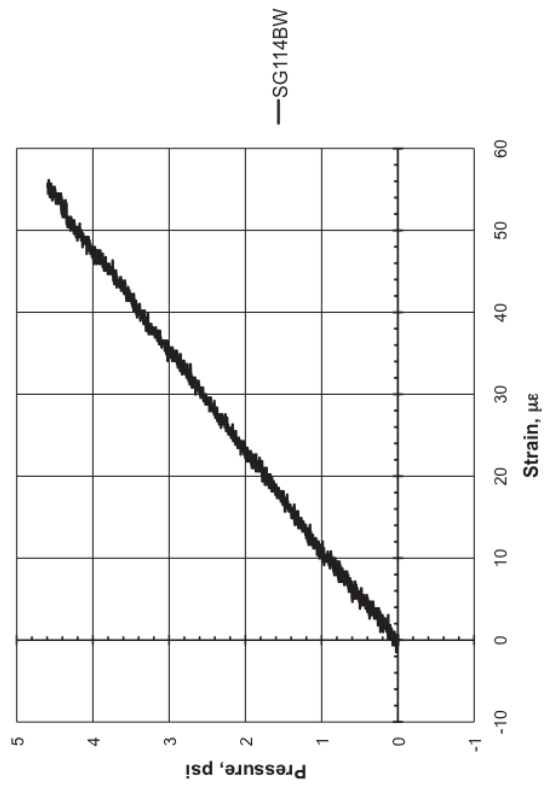


Figure B124. Checkout test 2, strain gage SG114BW.

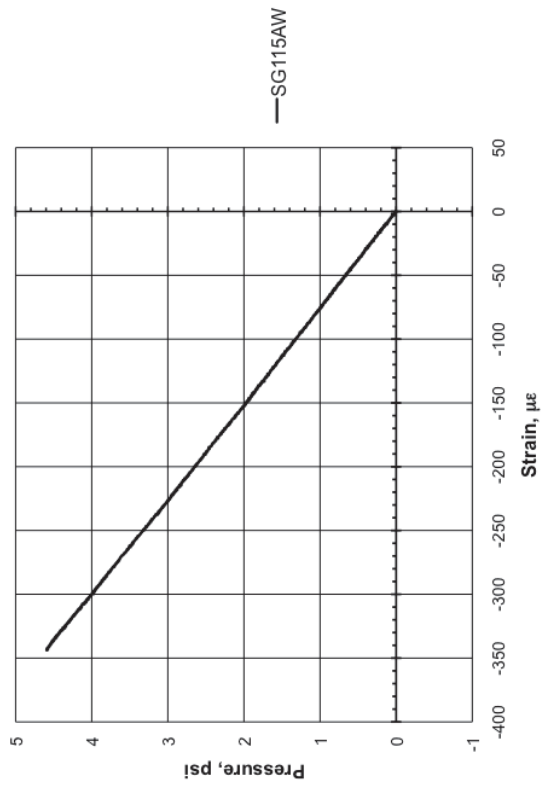


Figure B125. Checkout test 2, strain gage SG115AW.

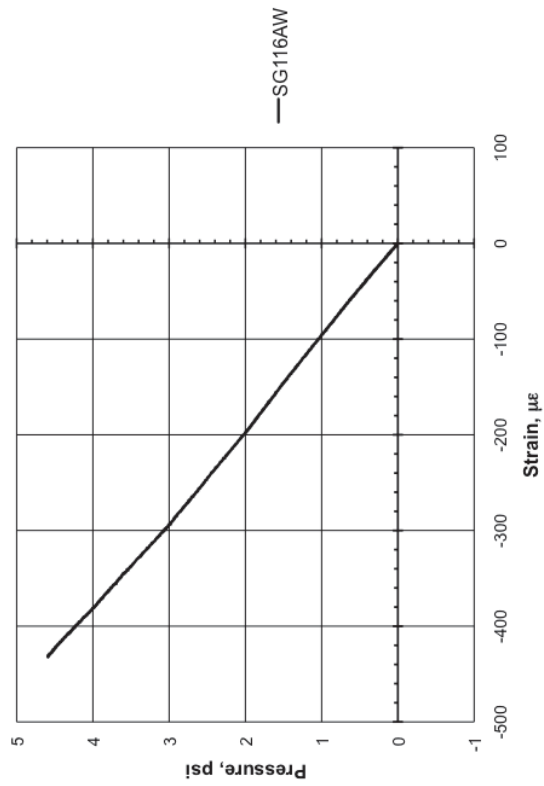


Figure B126. Checkout test 2, strain gage SG116AW.

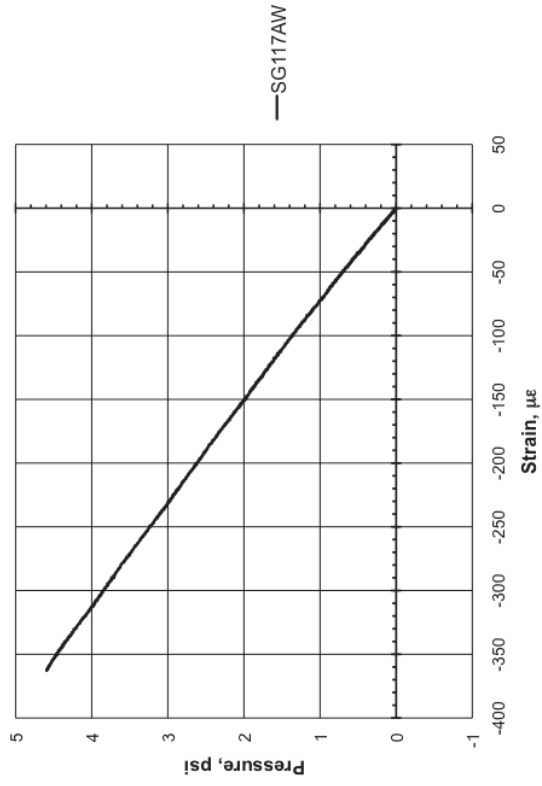


Figure B127. Checkout test 2, strain gage SG117AW.

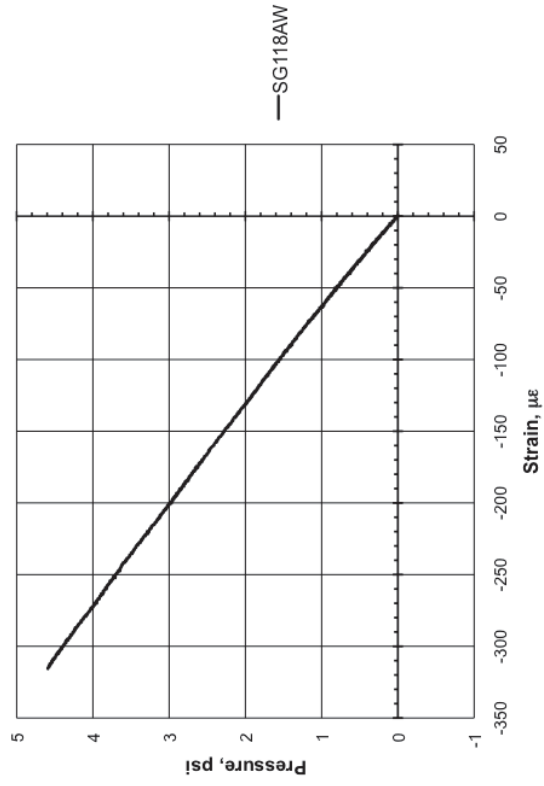


Figure B128. Checkout test 2, strain gage SG118AW.

**Appendix C:**  
**1P Test DCDT and Strain Gage Plots**

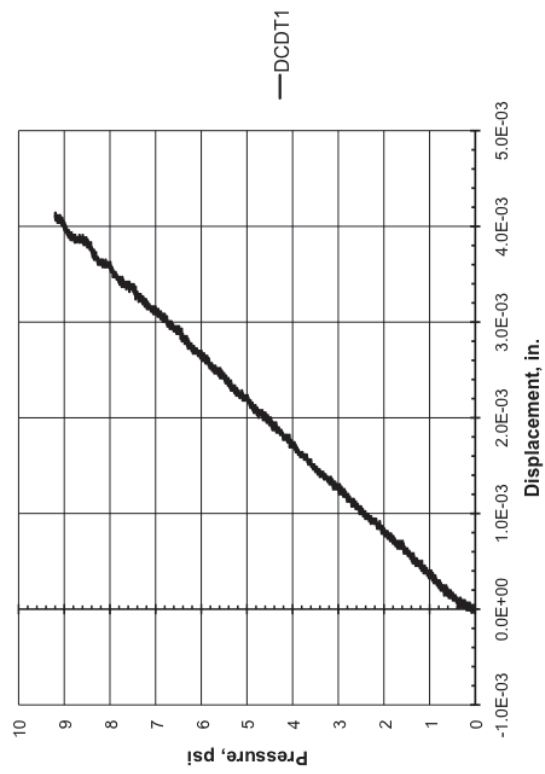


Figure C1. 1P test, DCDT1.

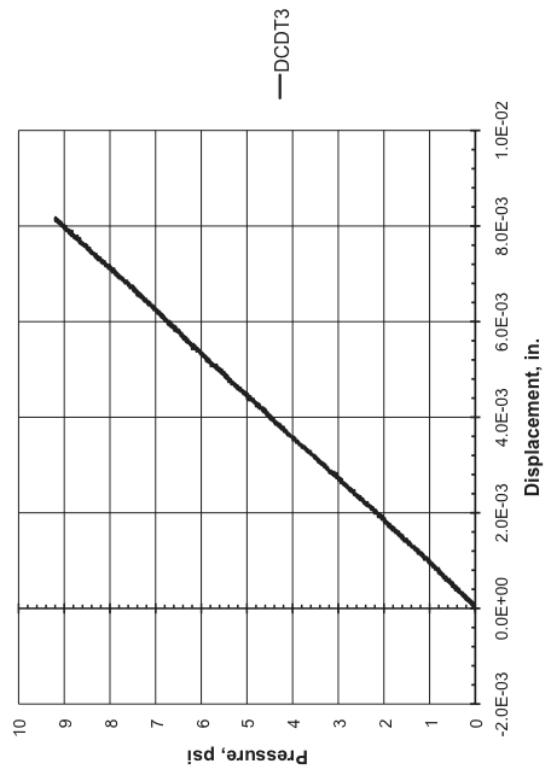


Figure C3. 1P test, DCDT3.

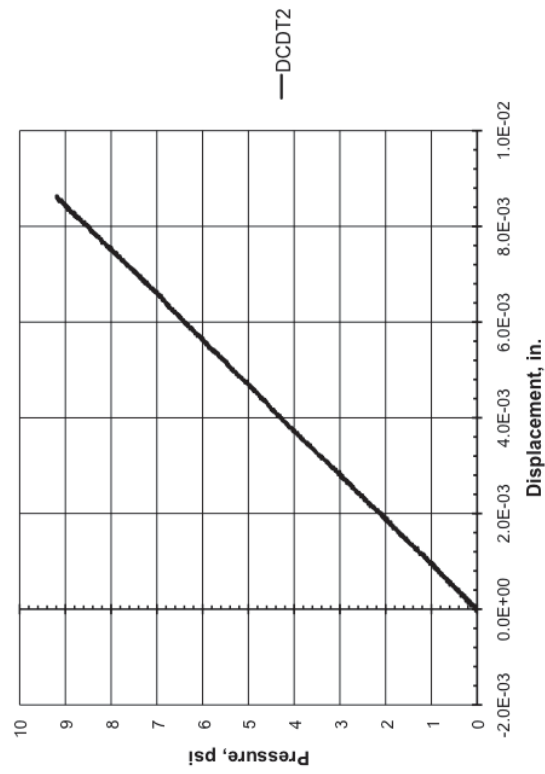


Figure C2. 1P test, DCDT2.

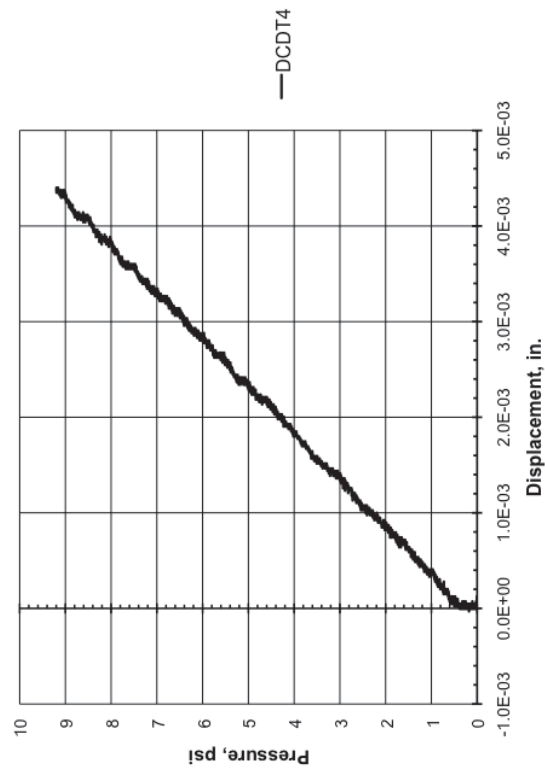
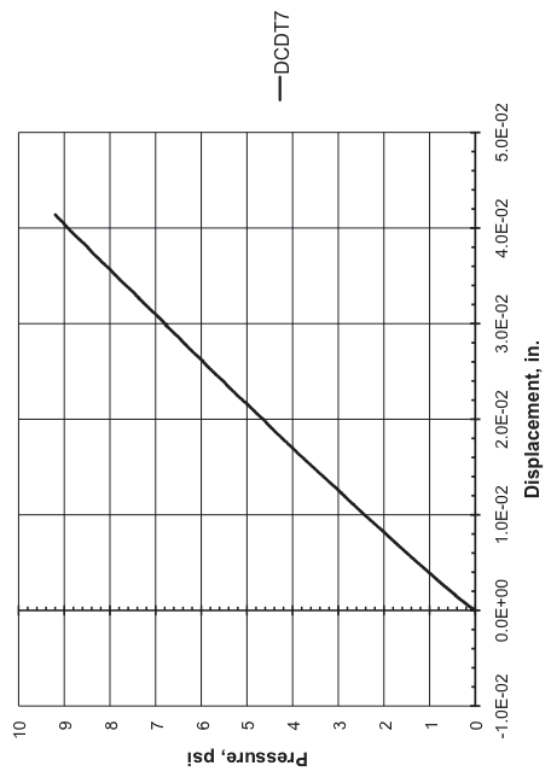
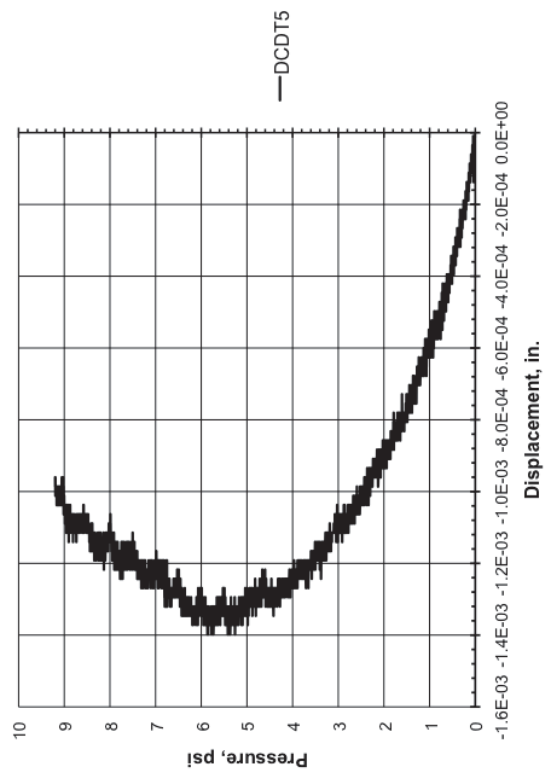
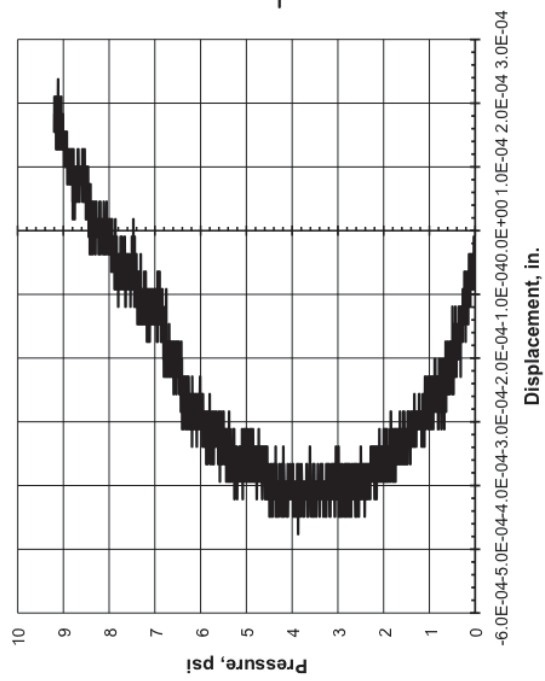
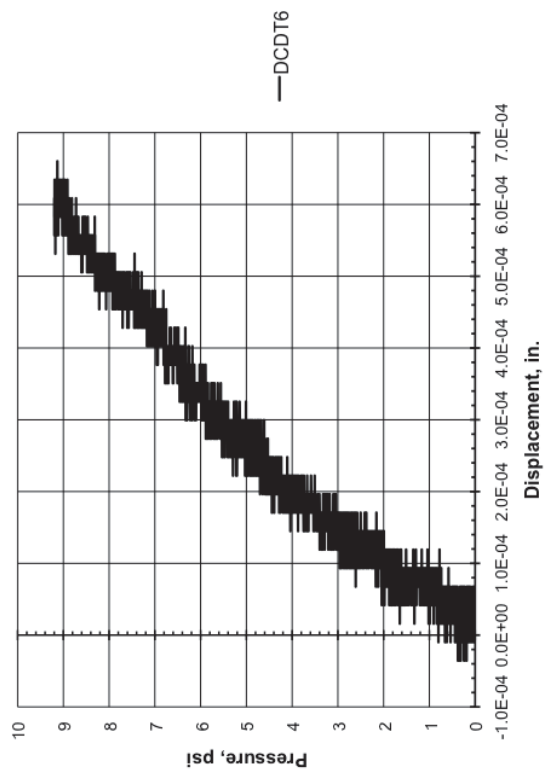


Figure C4. 1P test, DCDT4.



C3



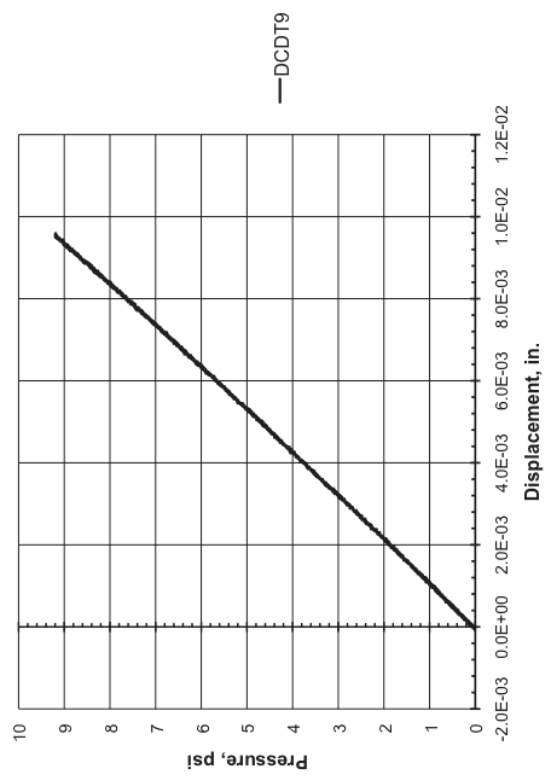


Figure C9. 1P test, DCDT9.

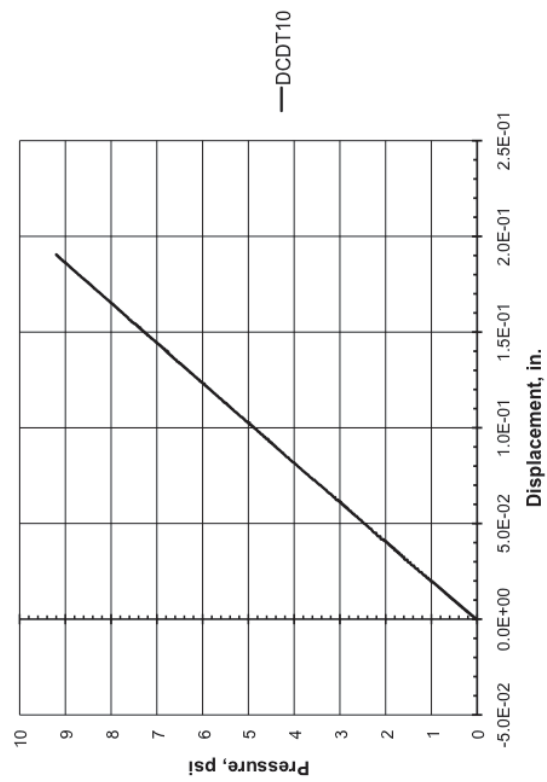


Figure C10. 1P test, DCDT10.

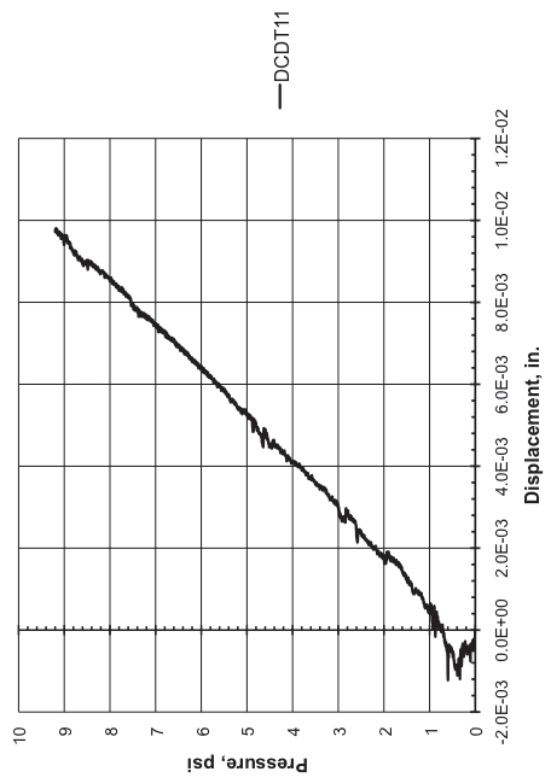


Figure C11. 1P test, DCDT11.

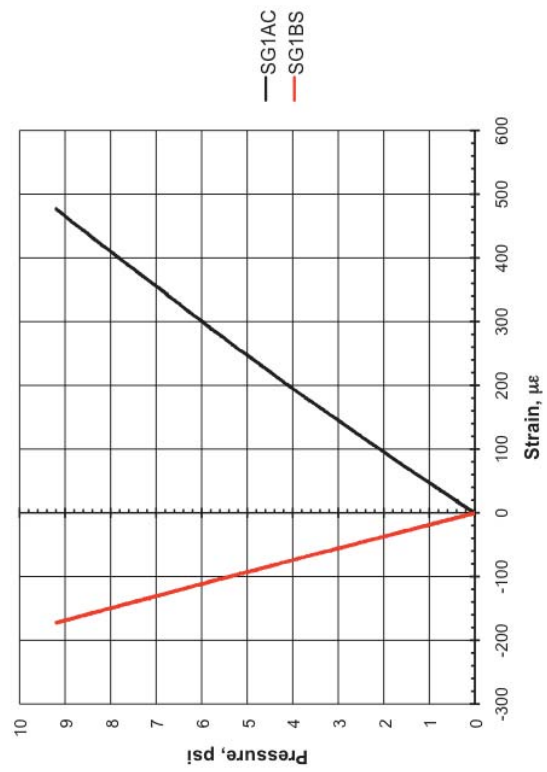


Figure C12. 1P test, strain gages SG1AC and SG1BS.



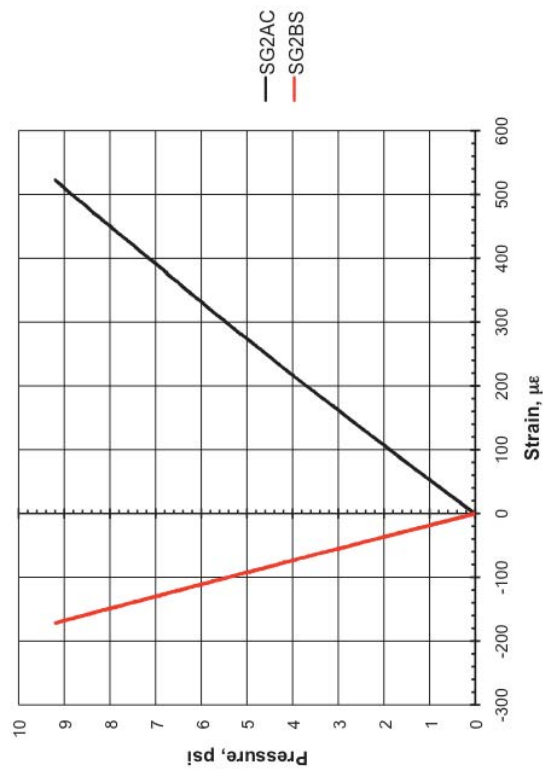


Figure C13. 1P test, strain gages SG2AC and SG2BS.

C5

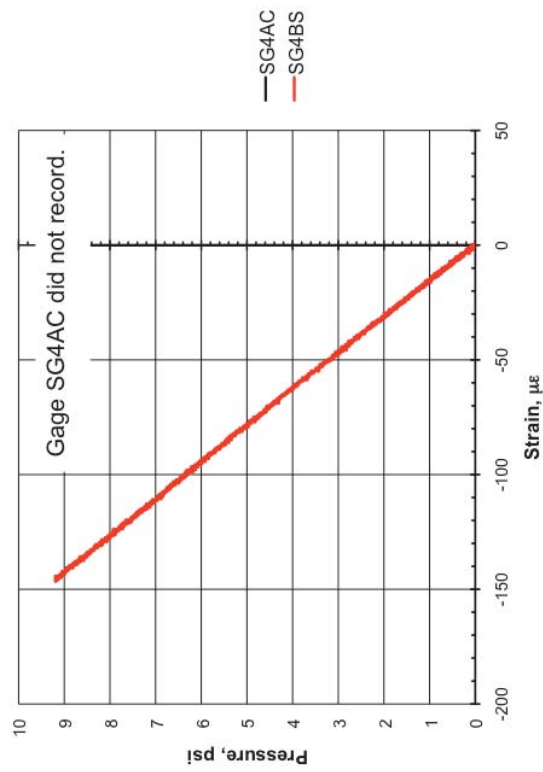


Figure C15. 1P test, strain gages SG4AC and SG4BS.

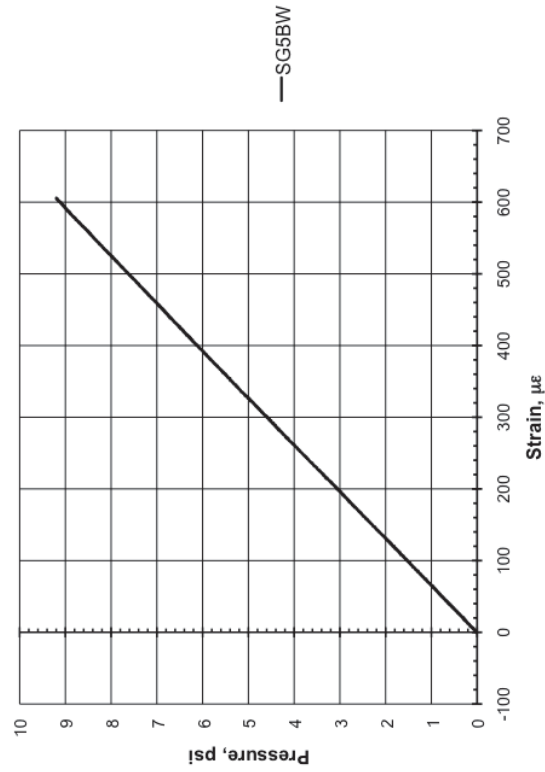


Figure C16. 1P test, strain gage SG5BW.

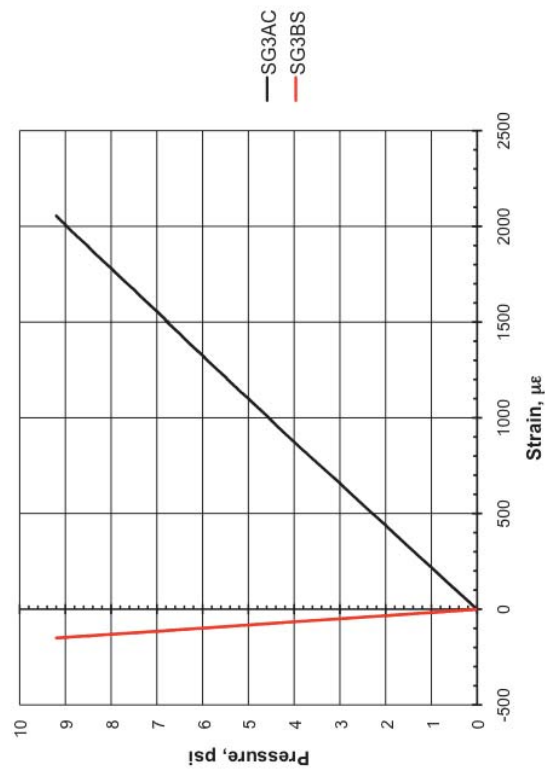


Figure C14. 1P test, strain gages SG3AC and SG3BS.

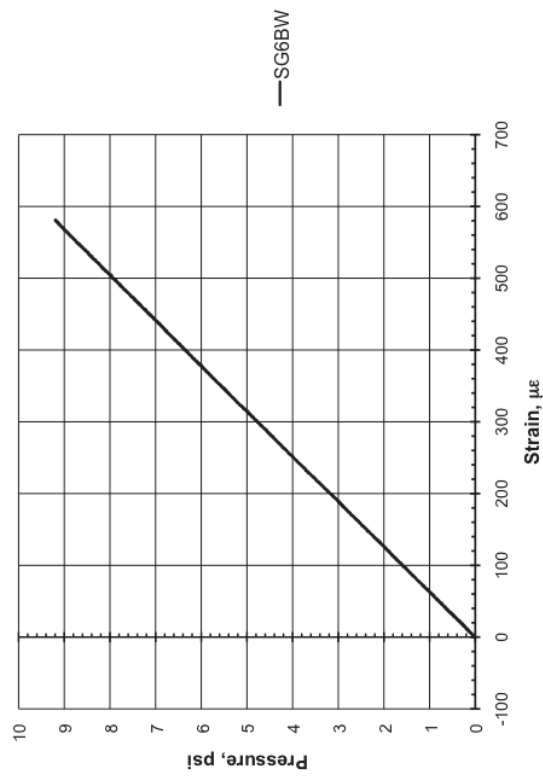


Figure C17. 1P test, strain gage SG6BW.

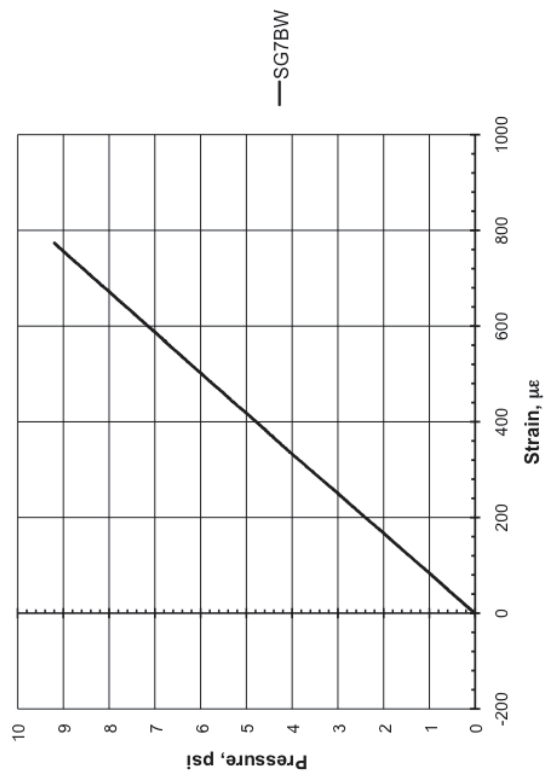


Figure C18. 1P test, strain gage SG7BW.

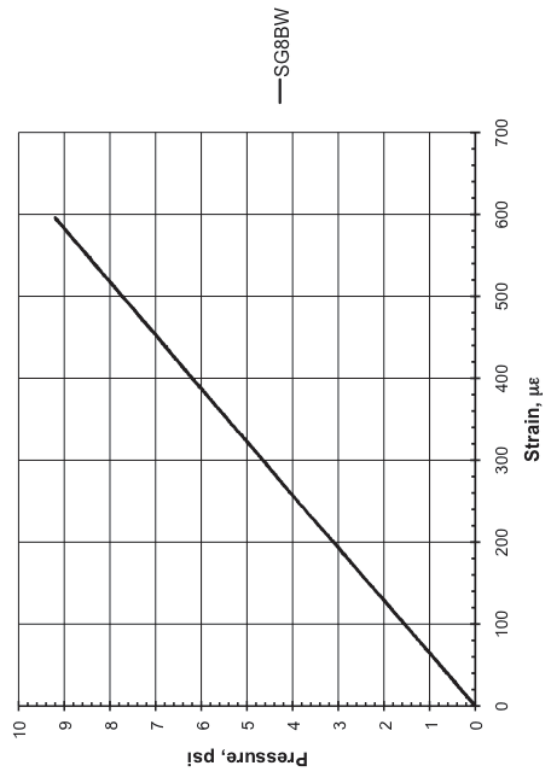


Figure C19. 1P test, strain gage SG8BW.

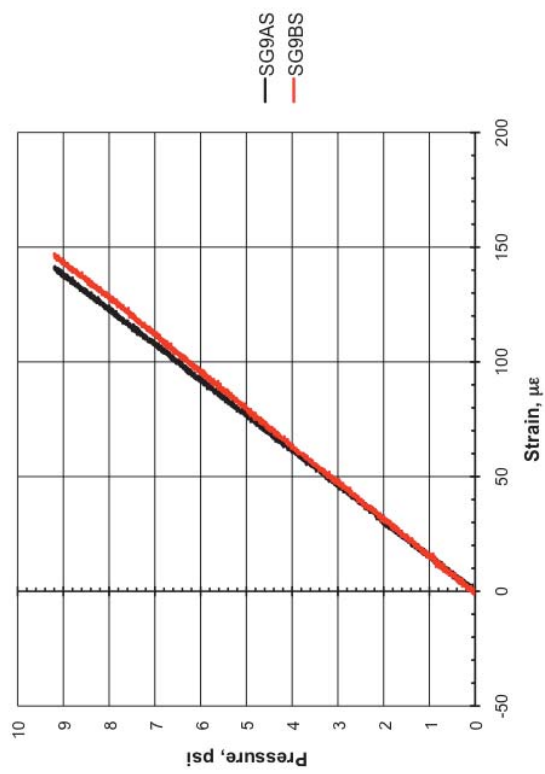


Figure C20. 1P test, strain gages SG9AS and SG9BS.

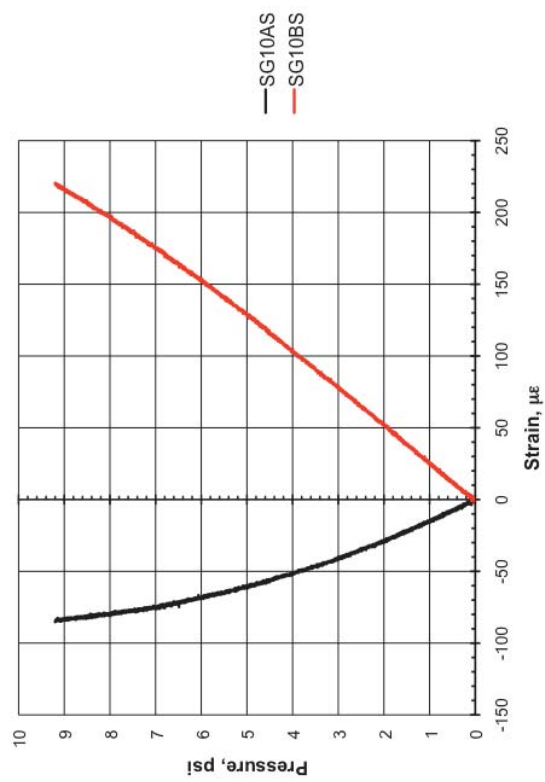


Figure C21. 1P test, strain gages SG10AS and SG10BS.

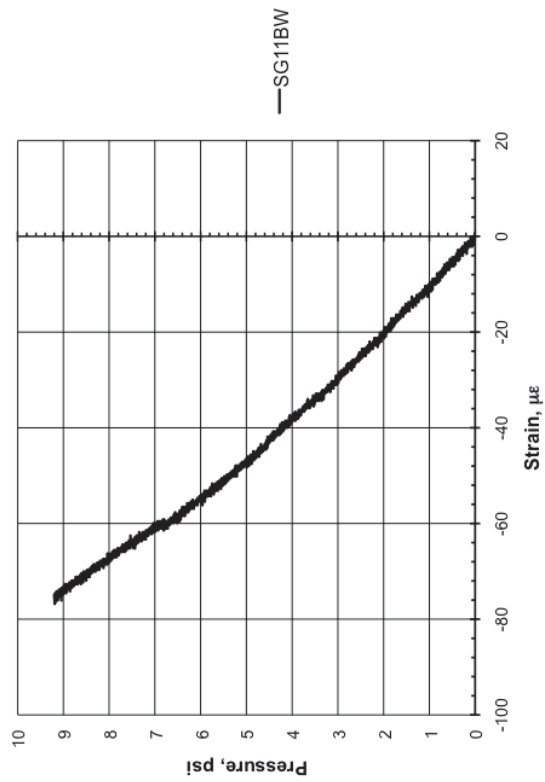


Figure C22. 1P test, strain gage SG11BW.

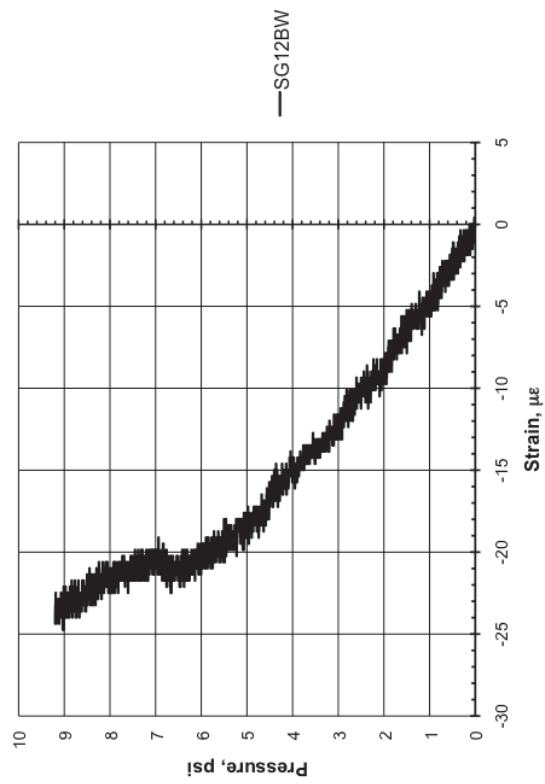


Figure C23. 1P test, strain gage SG12BW.

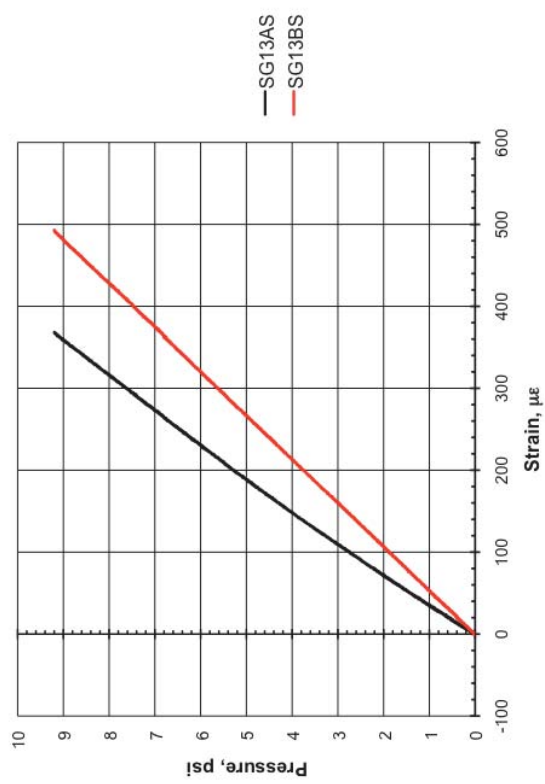


Figure C24. 1P test, strain gages SG13AS and SG13BS.

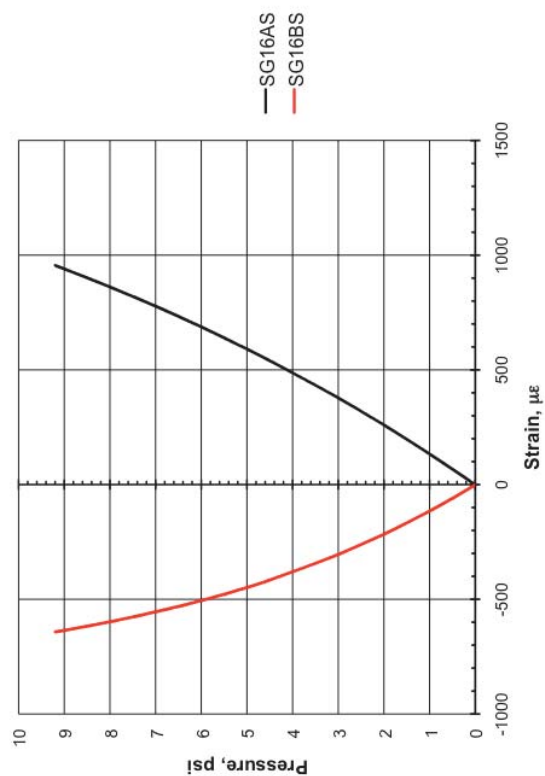


Figure C27. 1P test, strain gages SG16AS and SG16BS.

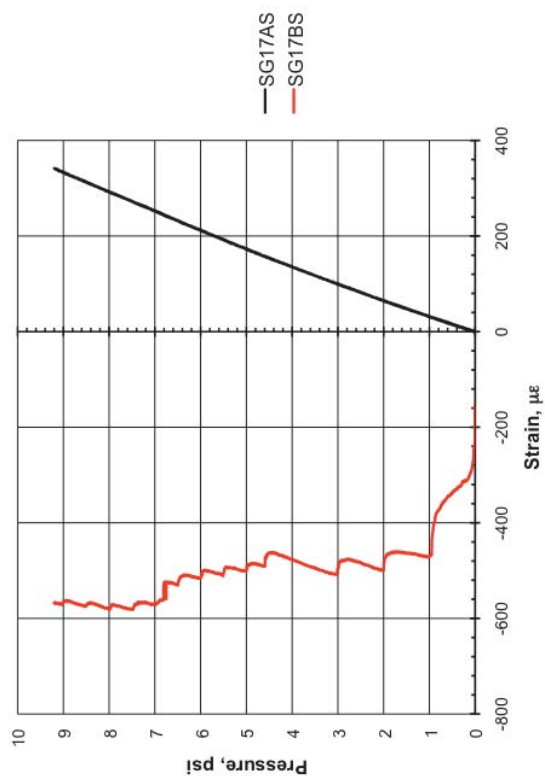


Figure C28. 1P test, strain gages SG17AS and SG17BS.

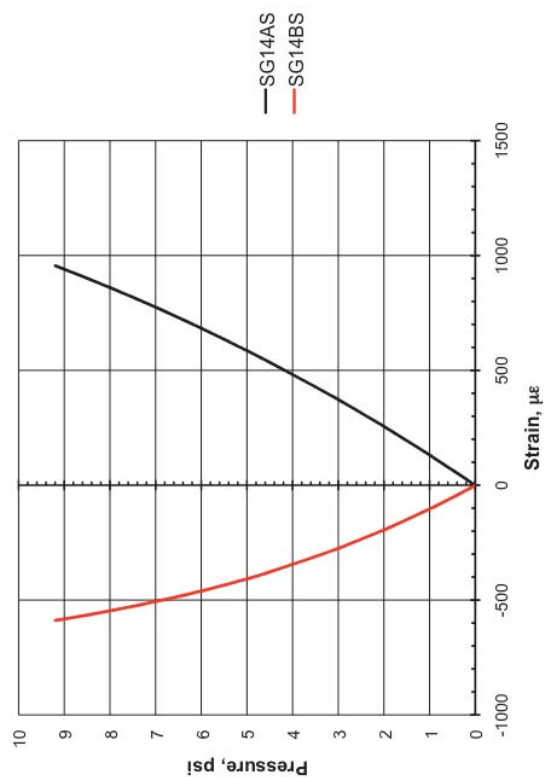


Figure C25. 1P test, strain gages SG14AS and SG14BS.

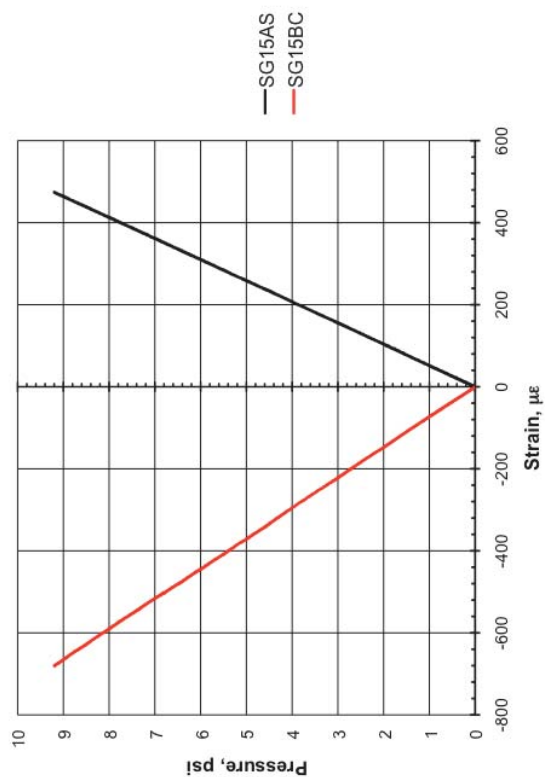


Figure C26. 1P test, strain gages SG15AS and SG15BC.

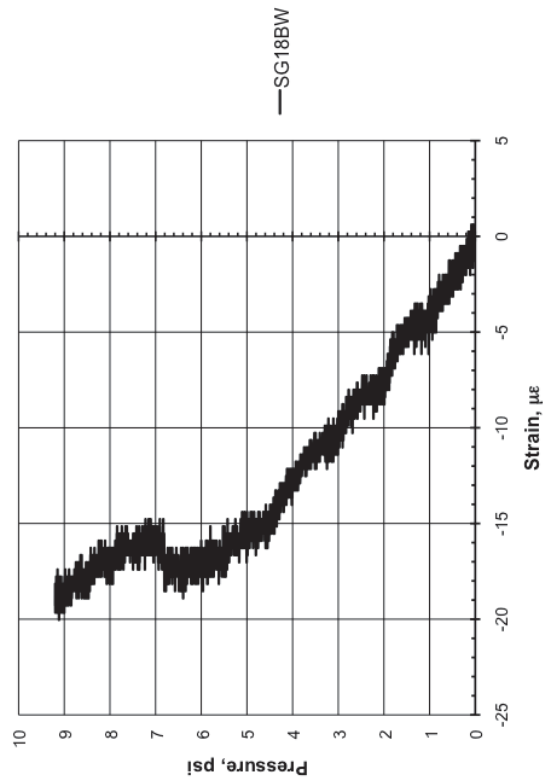


Figure C29. 1P test, strain gage SG18BW.

C9

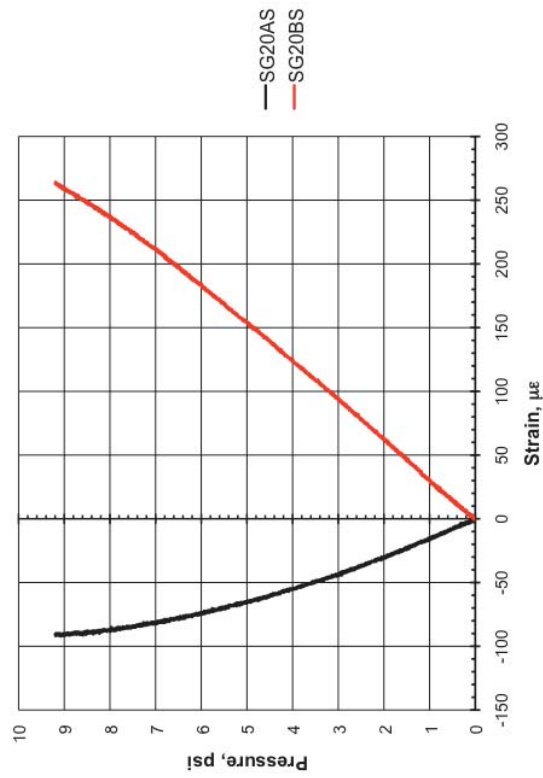


Figure C31. 1P test, strain gages SG20AS and SG20BS.

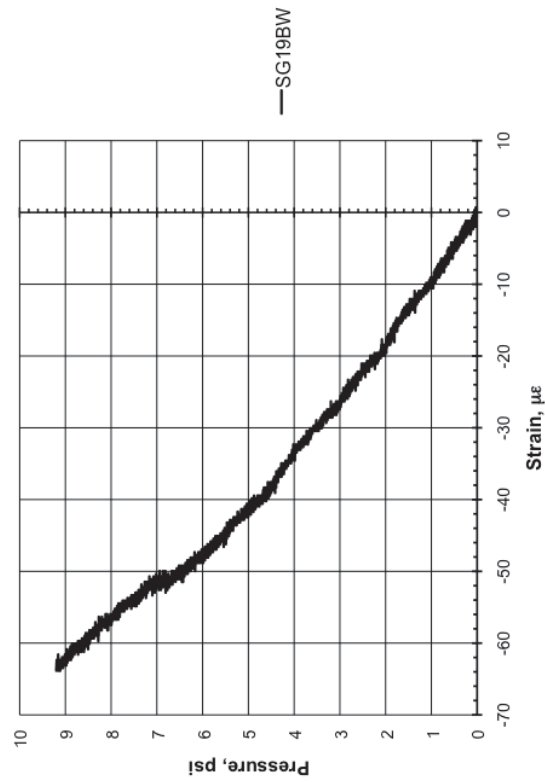


Figure C30. 1P test, strain gage SG19BW.

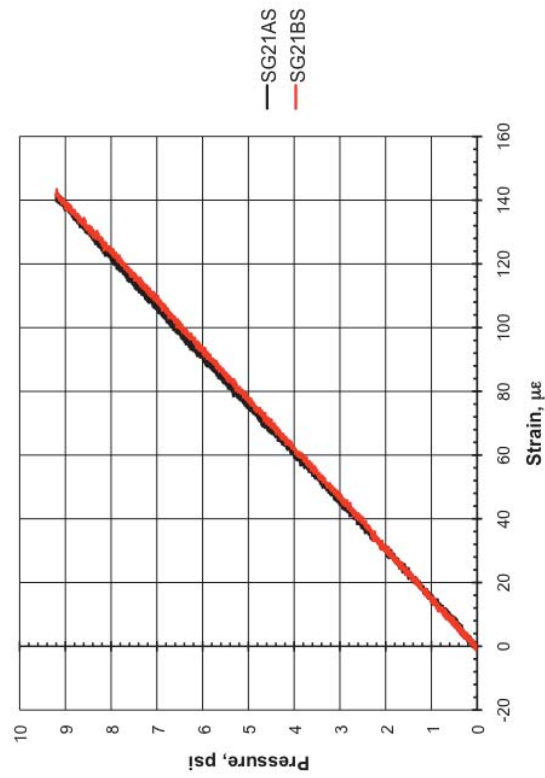


Figure C32. 1P test, strain gages SG21AS and SG21BS.

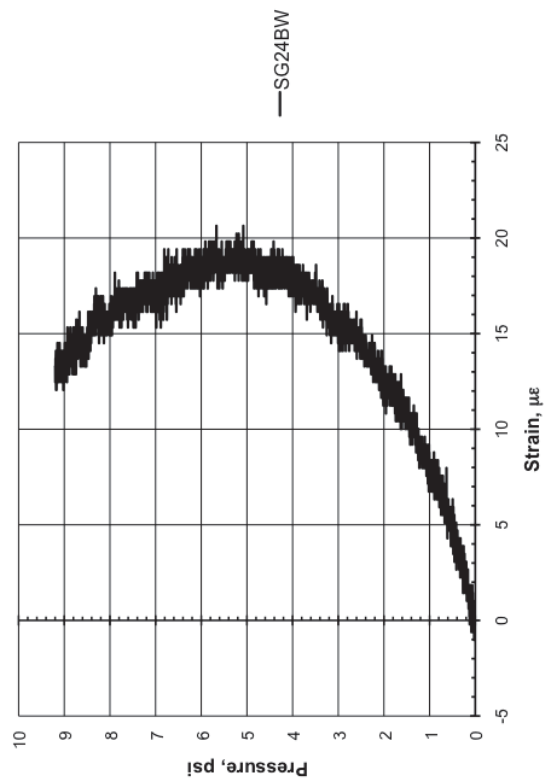


Figure C35. 1P test, strain gage SG24BW.

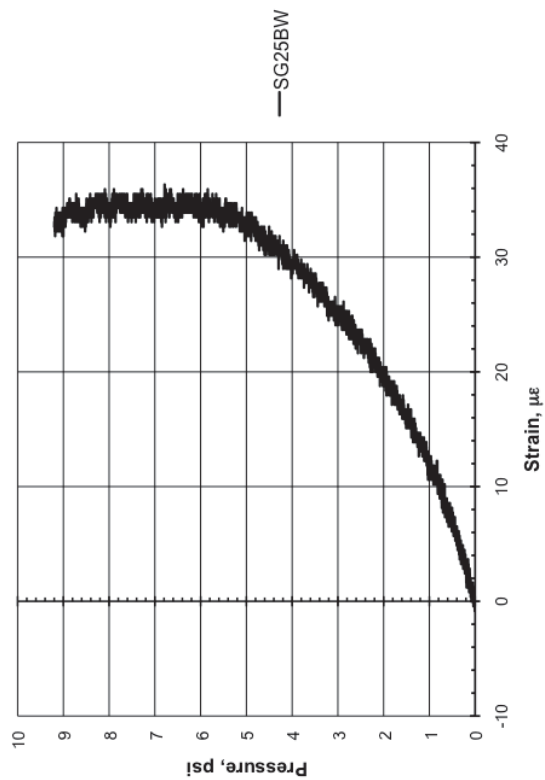


Figure C36. 1P test, strain gage SG25BW.

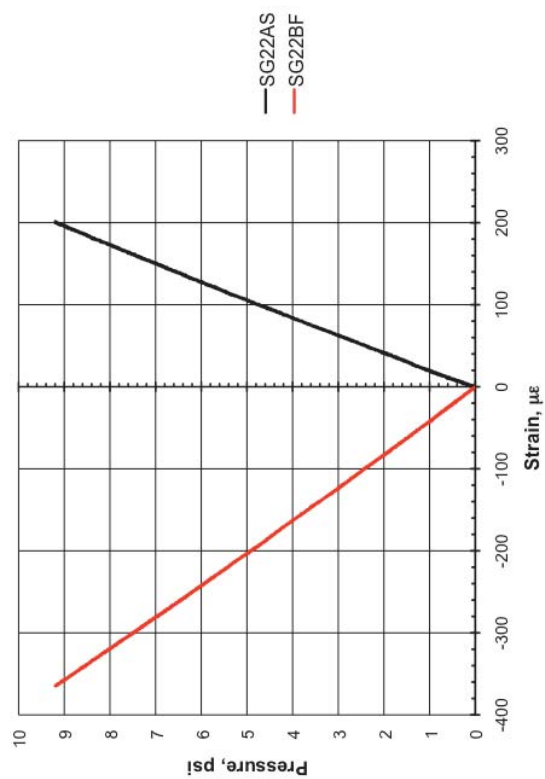


Figure C33. 1P test, strain gages SG22AS and SG22BF.

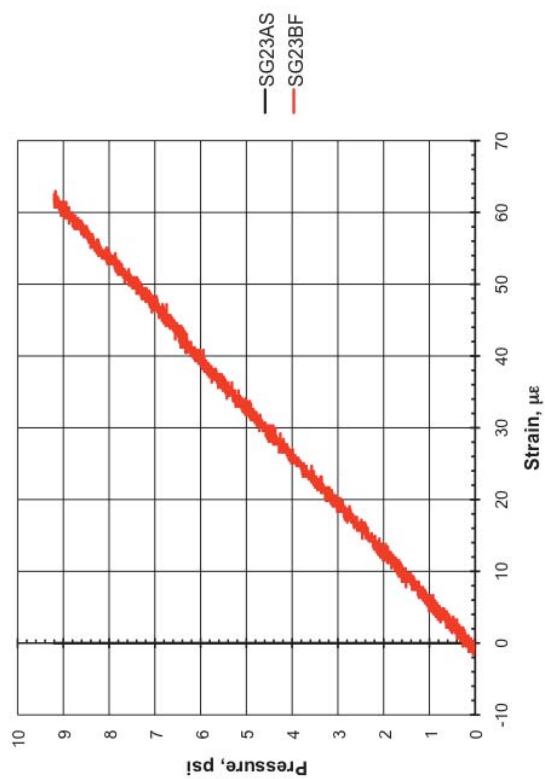


Figure C34. 1P test, strain gages SG23AS and SG23BF.

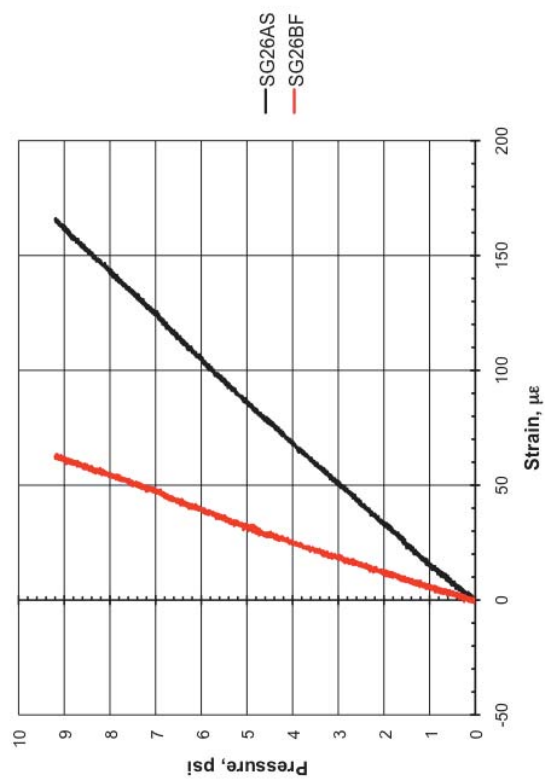


Figure C37. 1P test, strain gages SG26AS and SG26BF.

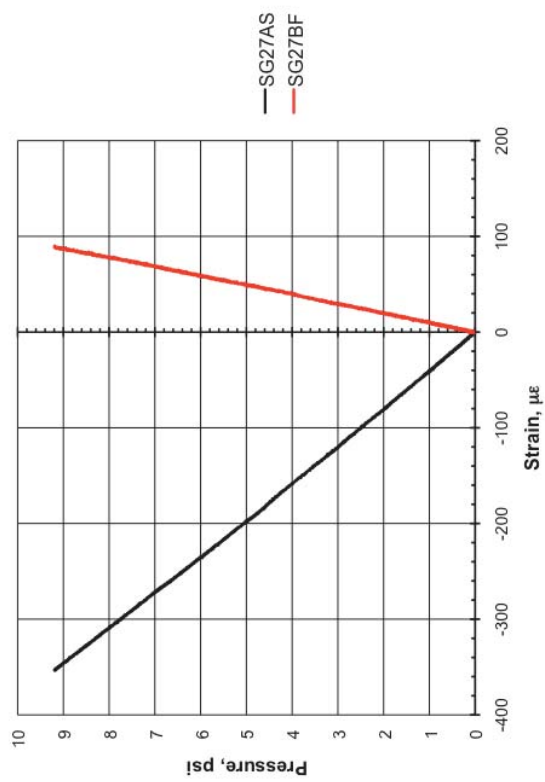


Figure C38. 1P test, strain gages SG27AS and SG27BF.

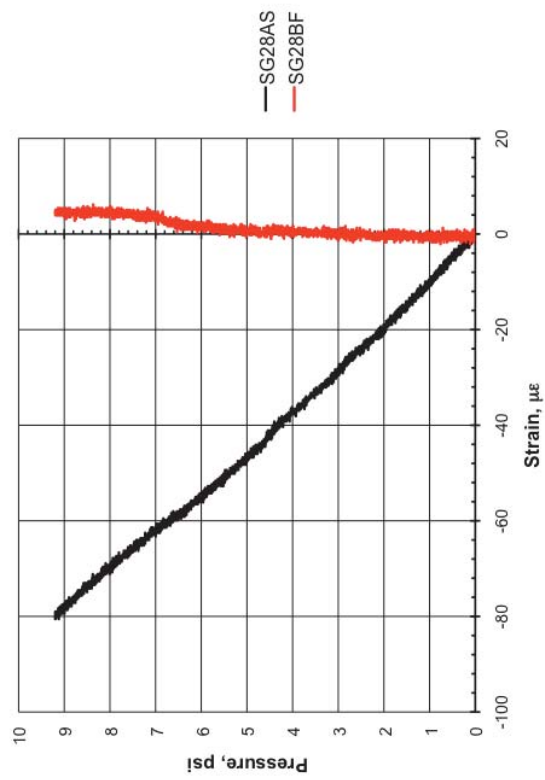


Figure C39. 1P test, strain gages SG28AS and SG28BF.

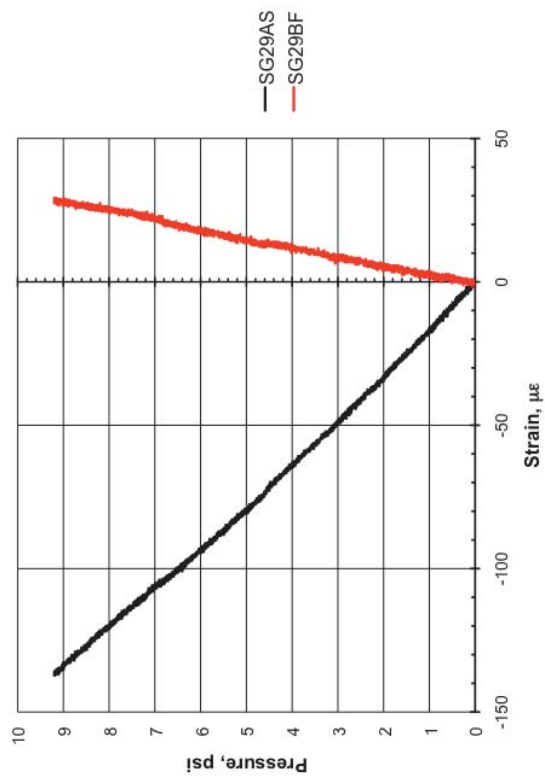


Figure C40. 1P test, strain gages SG29AS and SG29BF.

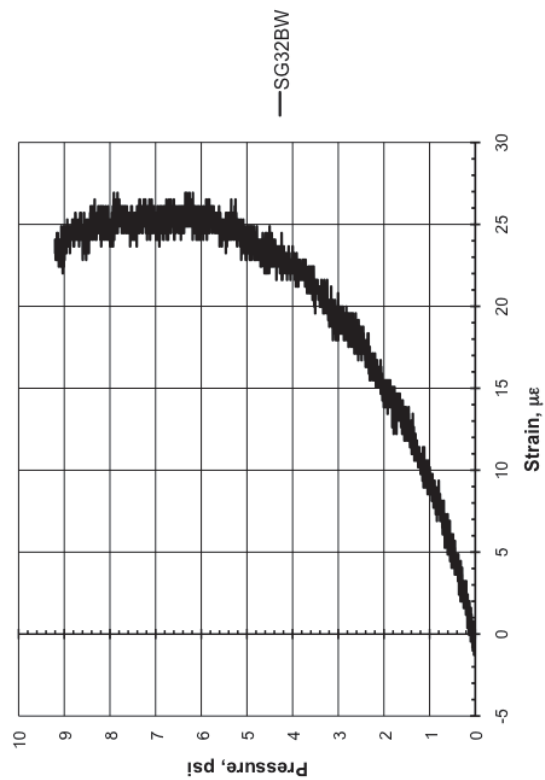


Figure C43. 1P test, strain gage SG32BW.

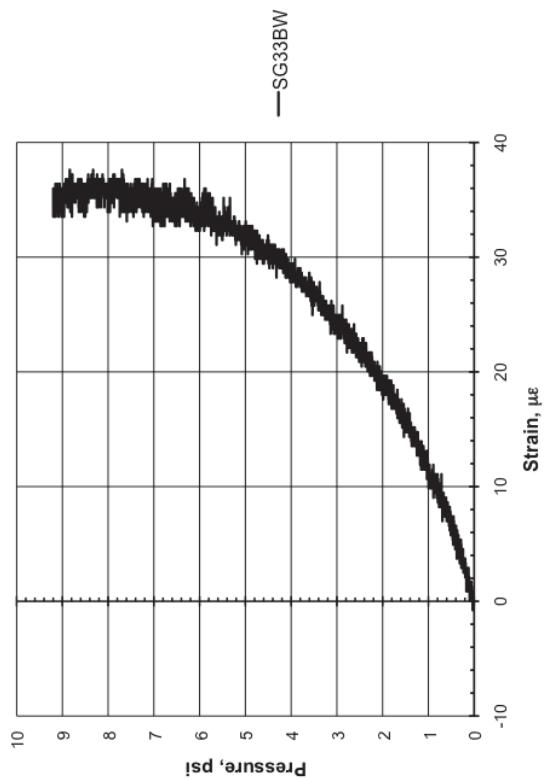


Figure C44. 1P test, strain gage SG33BW.

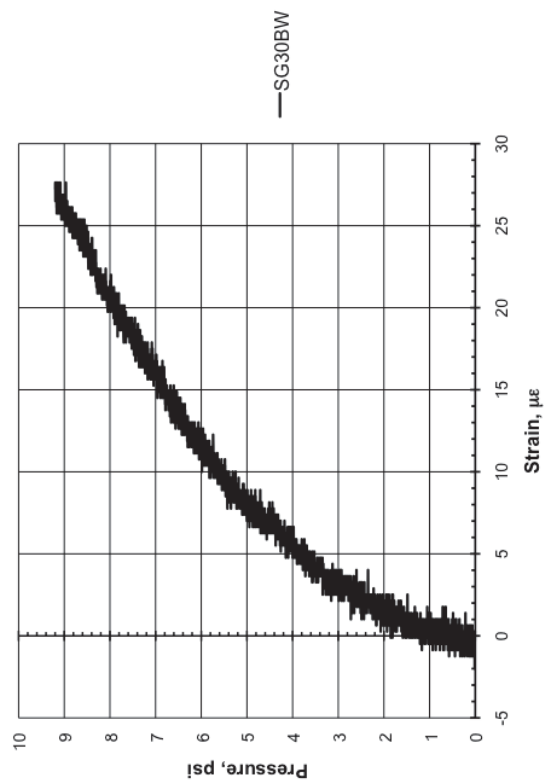


Figure C41. 1P test, strain gage SG30BW.

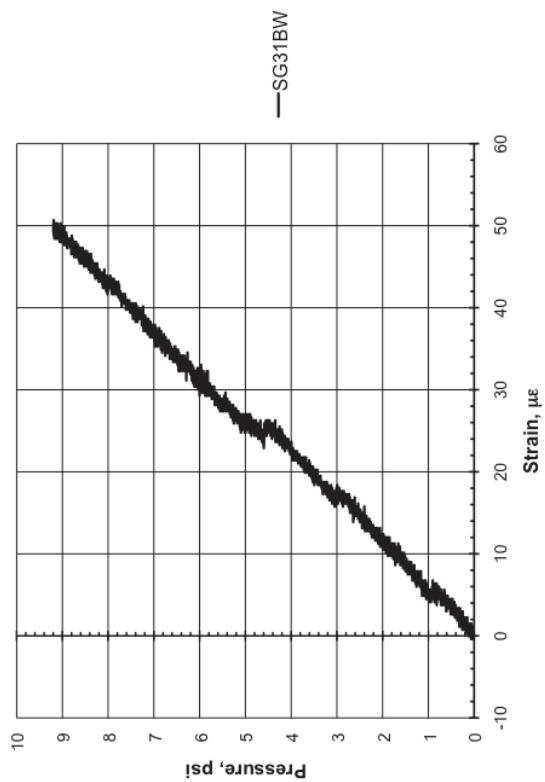


Figure C42. 1P test, strain gage SG31BW.



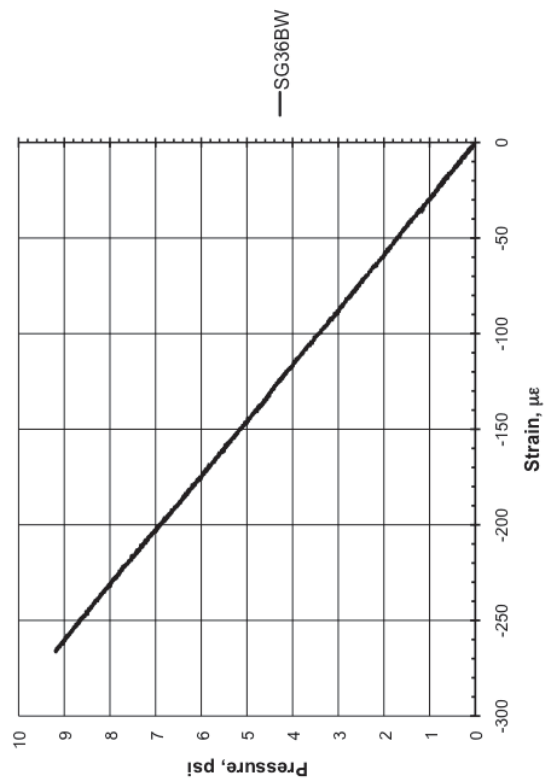


Figure C47. 1P test, strain gage SG36BW.

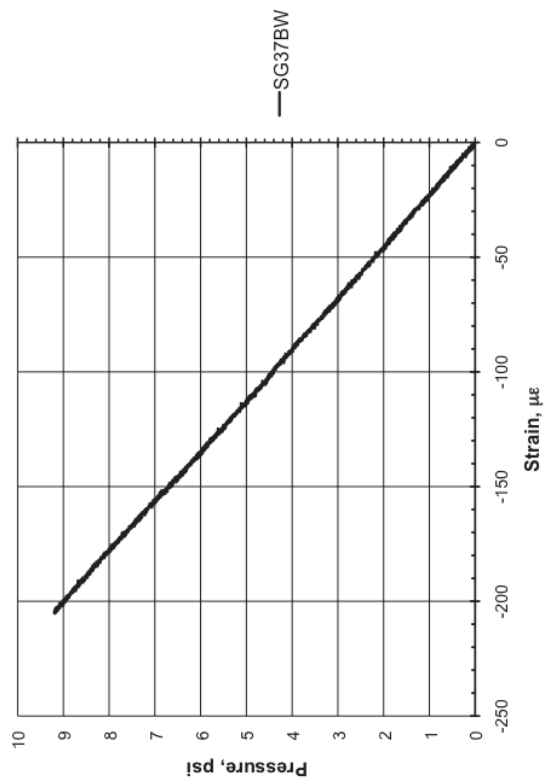


Figure C48. 1P test, strain gage SG37BW.

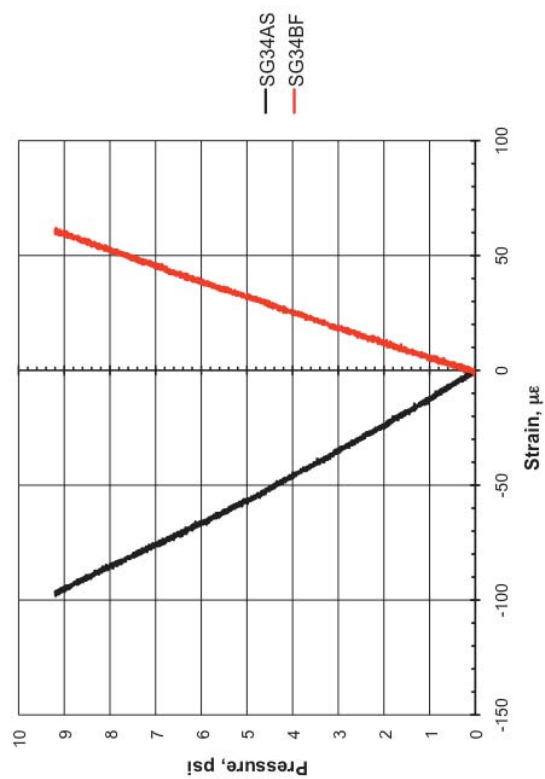


Figure C45. 1P test, strain gages SG34AS and SG34BF.

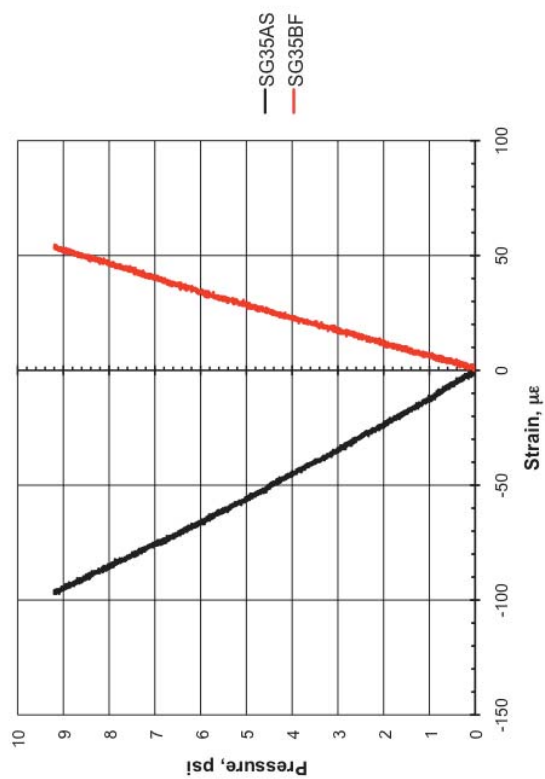


Figure C46. 1P test, strain gages SG35AS and SG35BF.

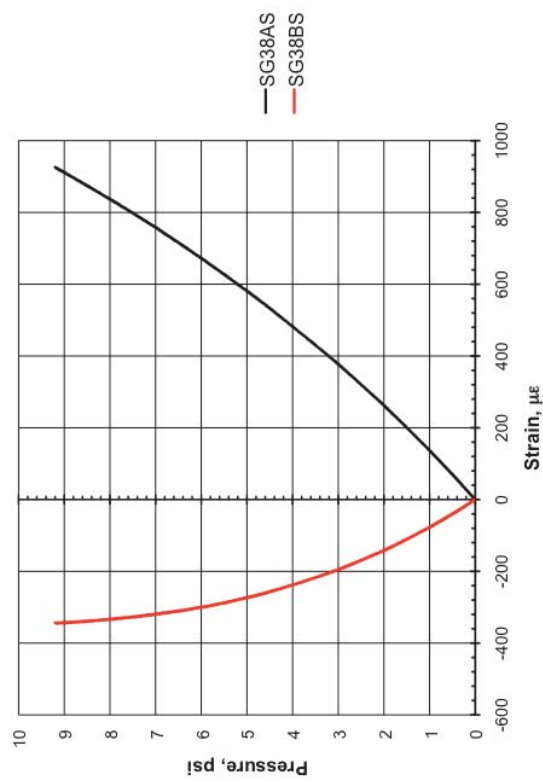


Figure C49. 1P test, strain gages SG38AS and SG38BS.

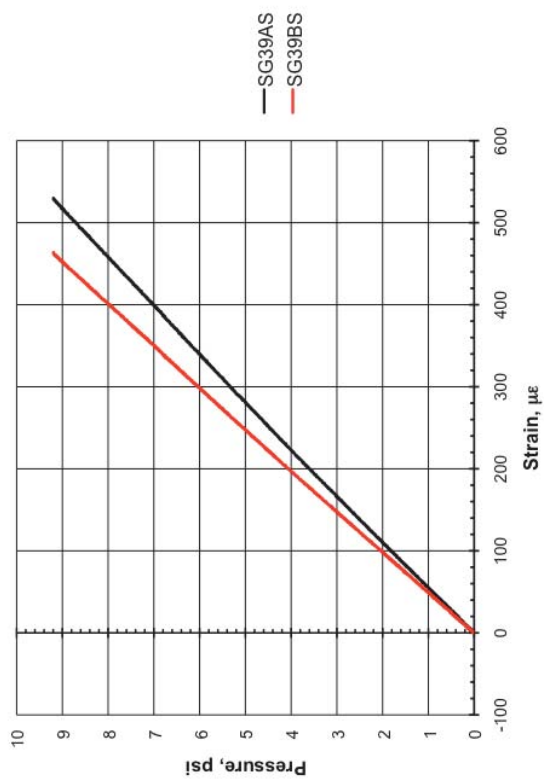


Figure C50. 1P test, strain gages SG39AS and SG39BS.

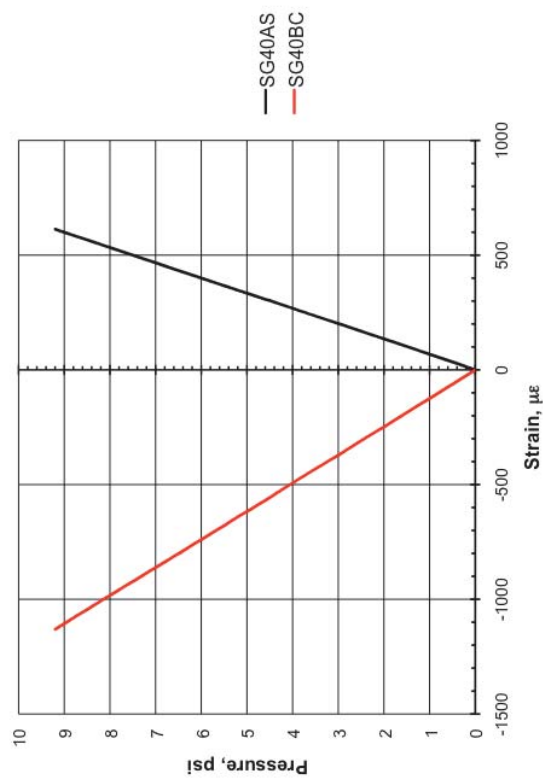


Figure C51. 1P test, strain gages SG40AS and SG40BC.

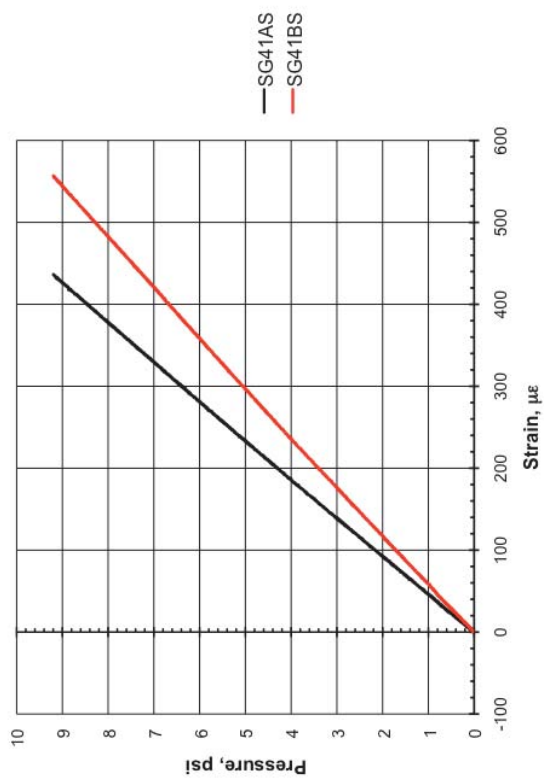


Figure C52. 1P test, strain gages SG41AS and SG41BS.

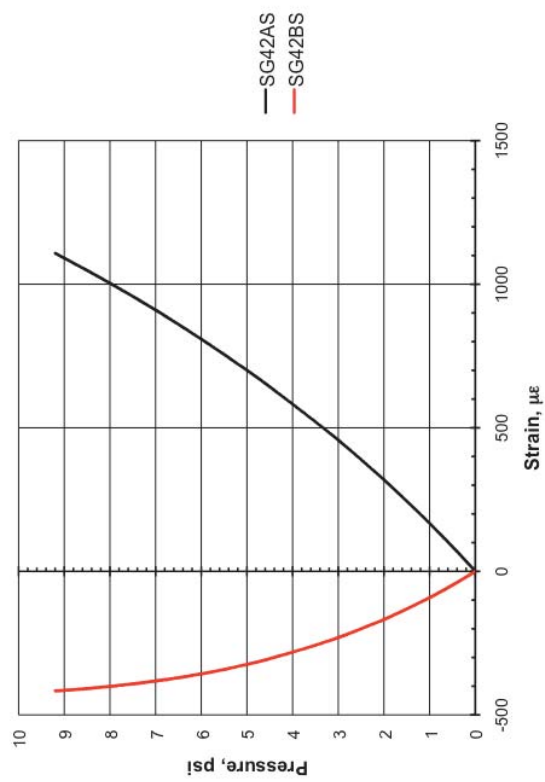


Figure C53. 1P test, strain gages SG42AS and SG42BS.

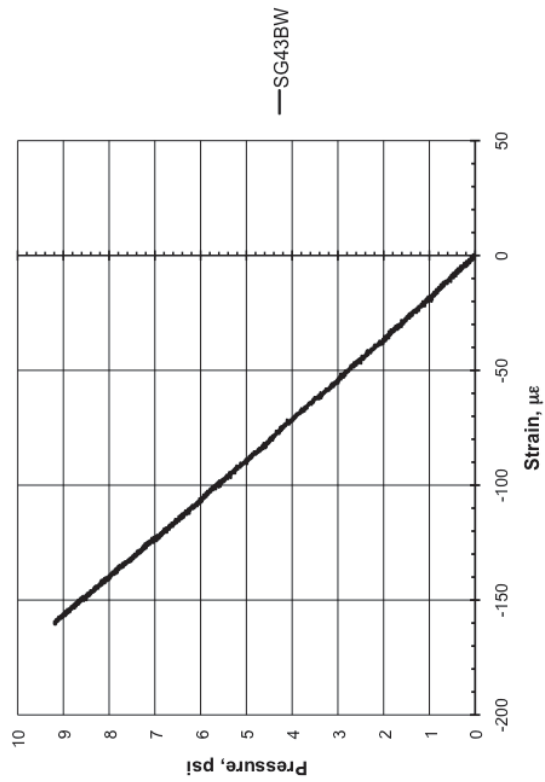


Figure C54. 1P test, strain gage SG43BW.

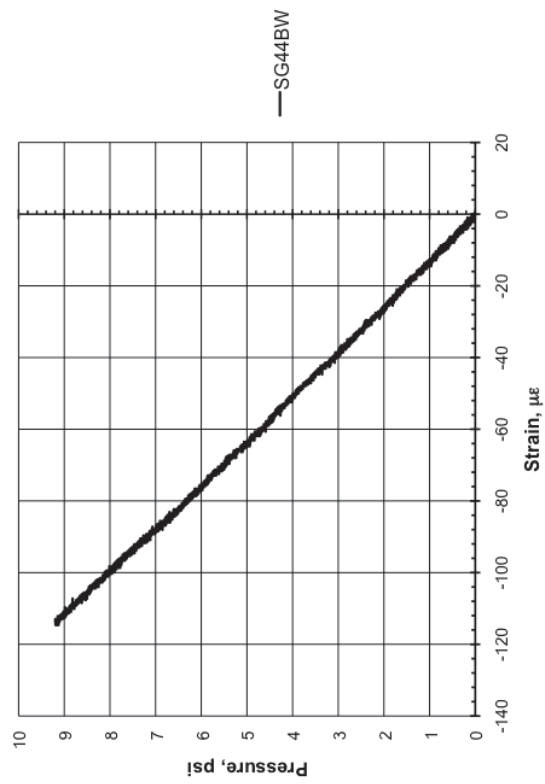


Figure C55. 1P test, strain gage SG44BW.

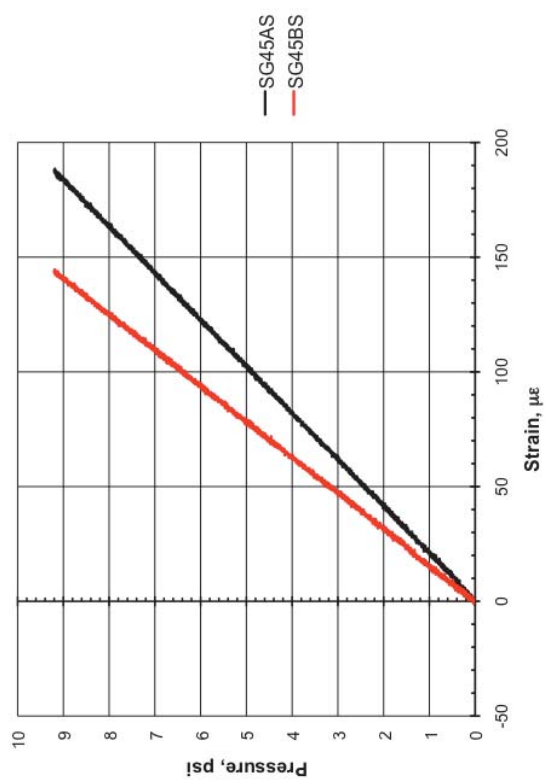


Figure C56. 1P test, strain gages SG45AS and SG45BS.

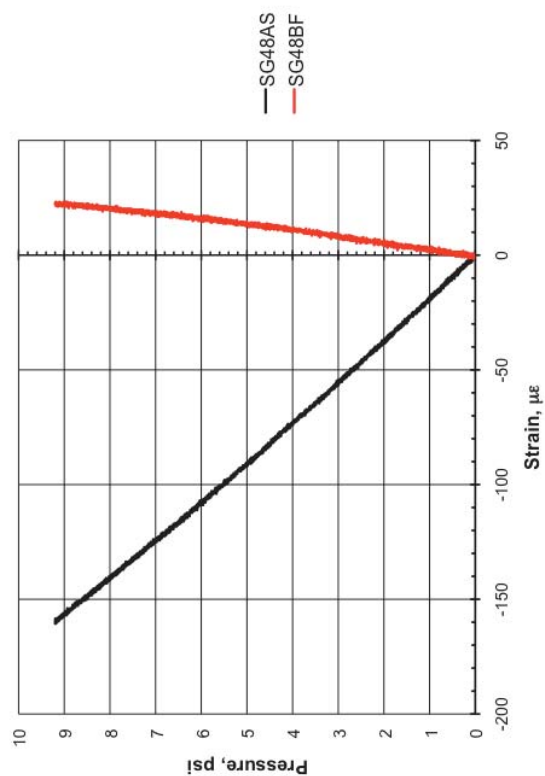


Figure C59. 1P test, strain gages SG48AS and SG48BF.

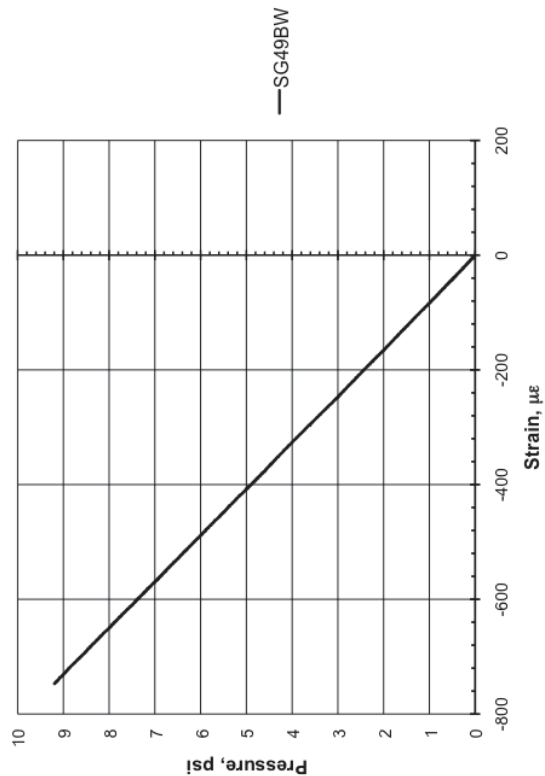


Figure C60. 1P test, strain gage SG49BW.

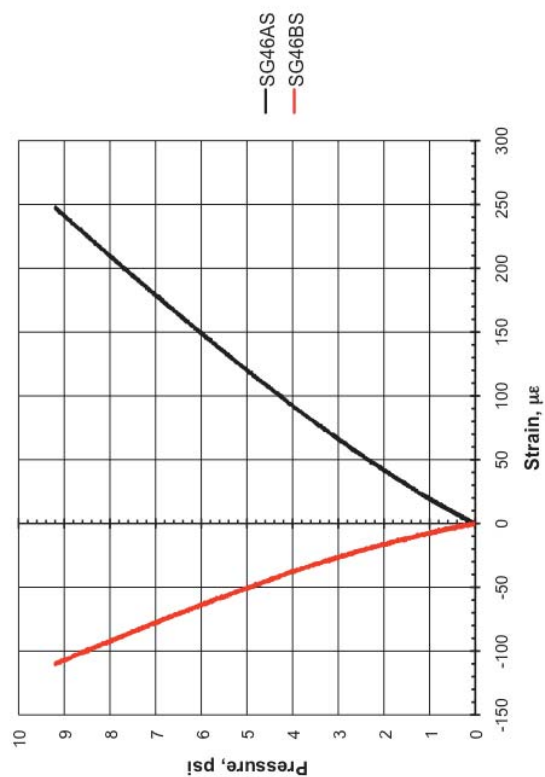


Figure C57. 1P test, strain gages SG46AS and SG46BS.

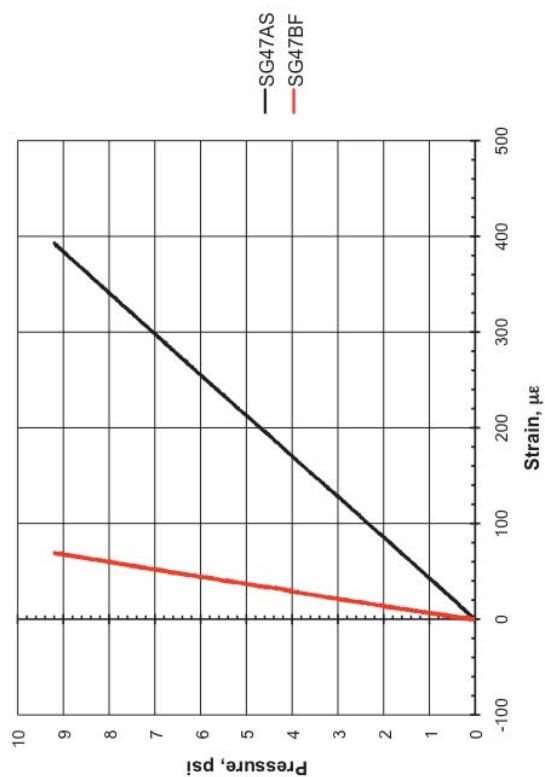


Figure C58. 1P test, strain gages SG47AS and SG47BF.

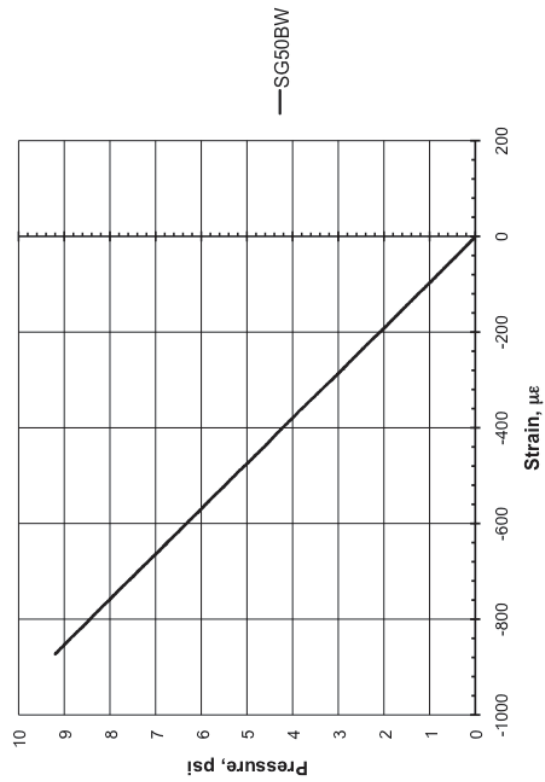


Figure C61. 1P test, strain gage SG50BW.

C17

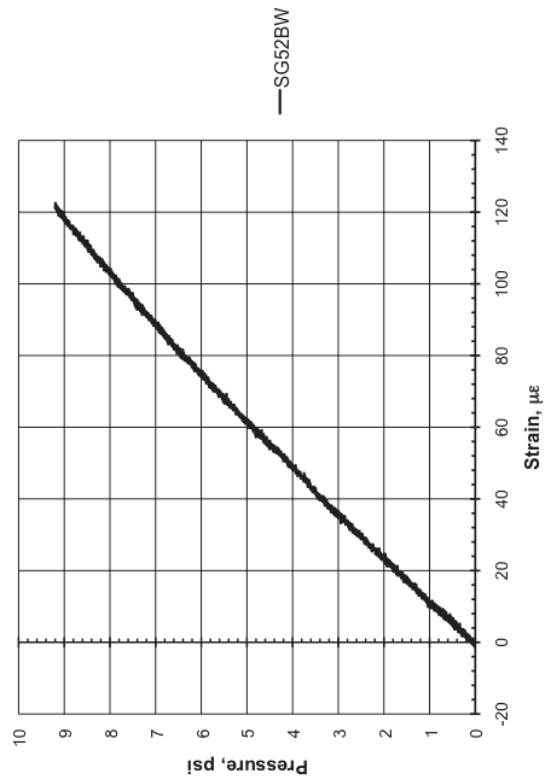


Figure C63. 1P test, strain gage SG52BW.

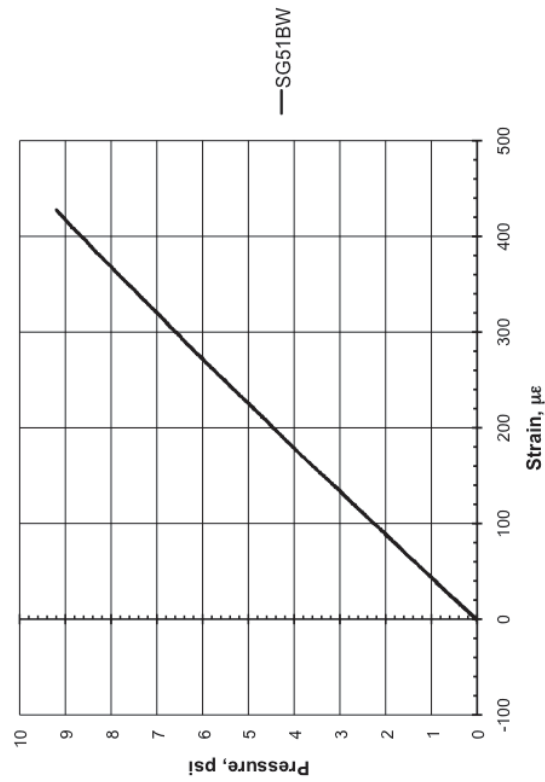


Figure C62. 1P test, strain gage SG51BW.

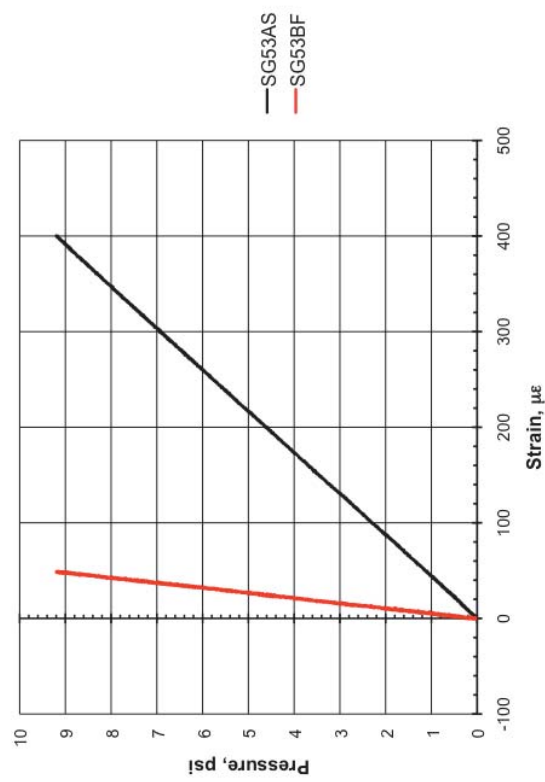


Figure C64. 1P test, strain gages SG53AS and SG53BF.

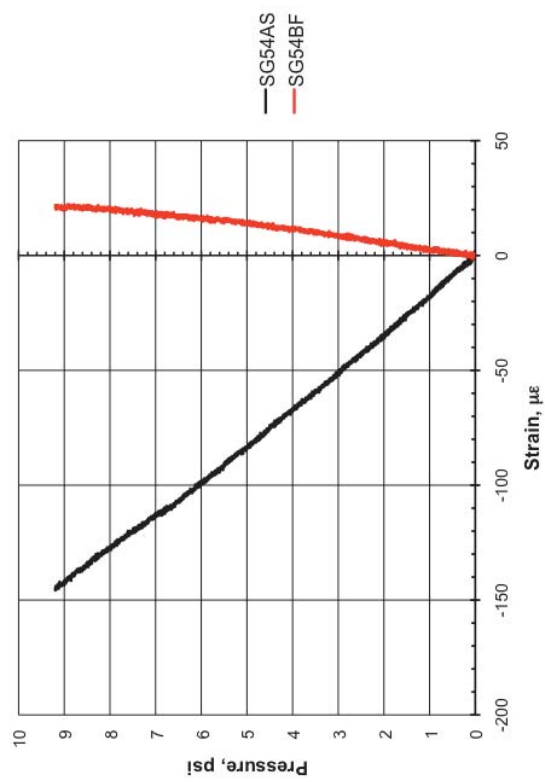


Figure C65. 1P test, strain gages SG54AS and SG54BF.

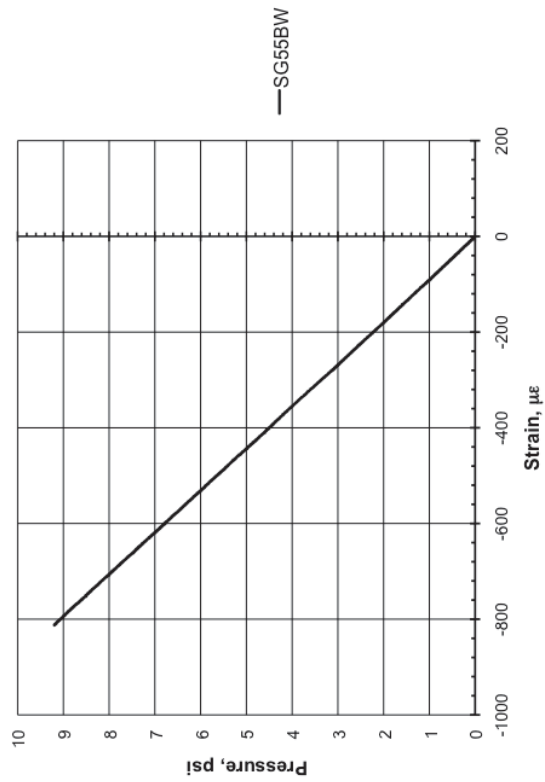


Figure C66. 1P test, strain gage SG55BW.

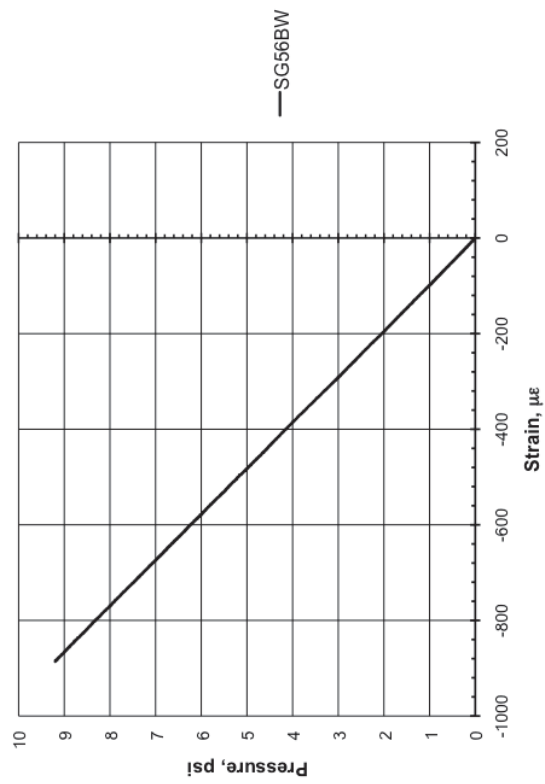


Figure C67. 1P test, strain gage SG56BW.

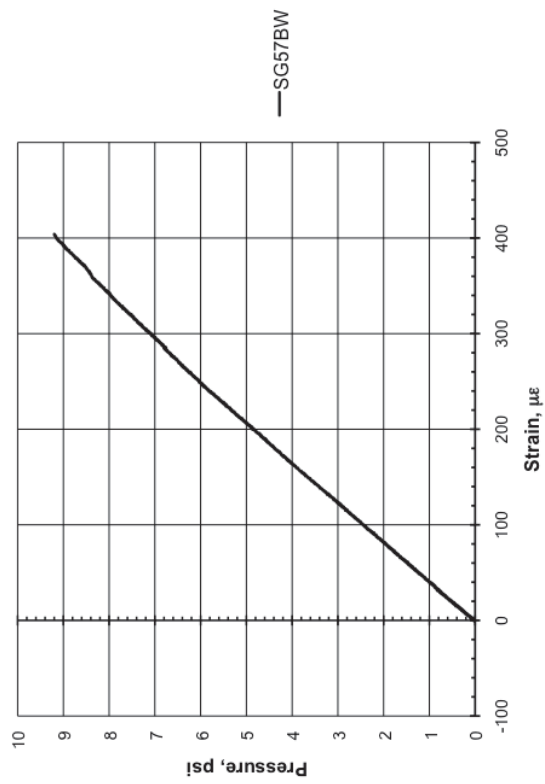


Figure C68. 1P test, strain gage SG57BW.

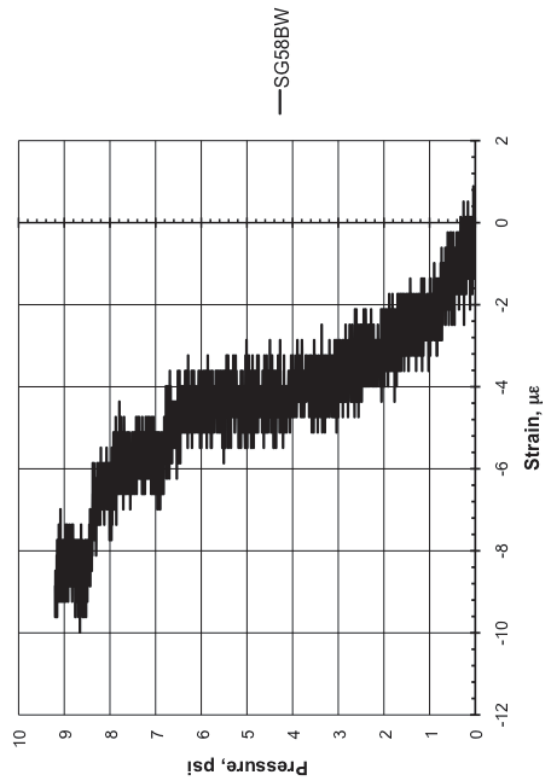


Figure C69. 1P test, strain gage SG58BW.

C19

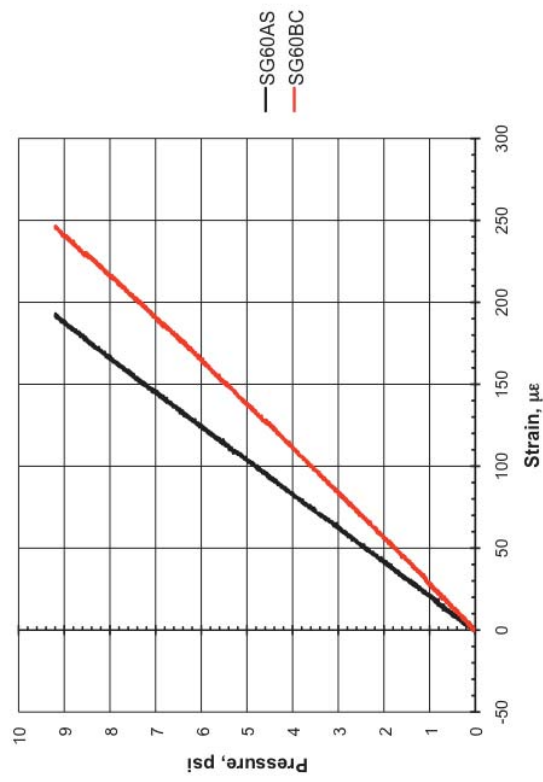


Figure C71. 1P test, strain gages SG60AS and SG60BC.

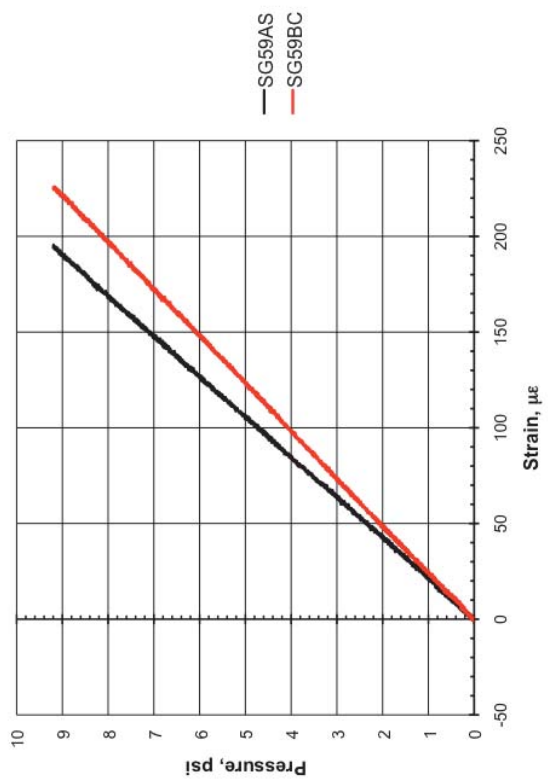


Figure C70. 1P test, strain gages SG59AS and SG59BC.

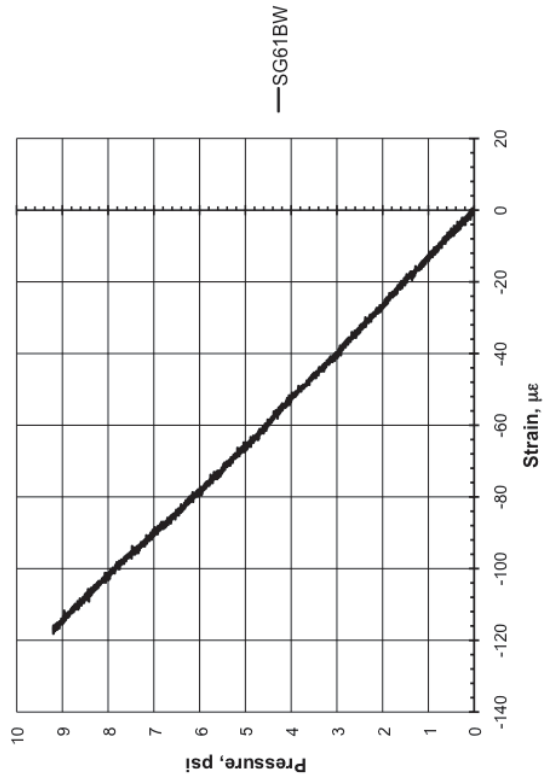


Figure C72. 1P test, strain gage SG61BW.

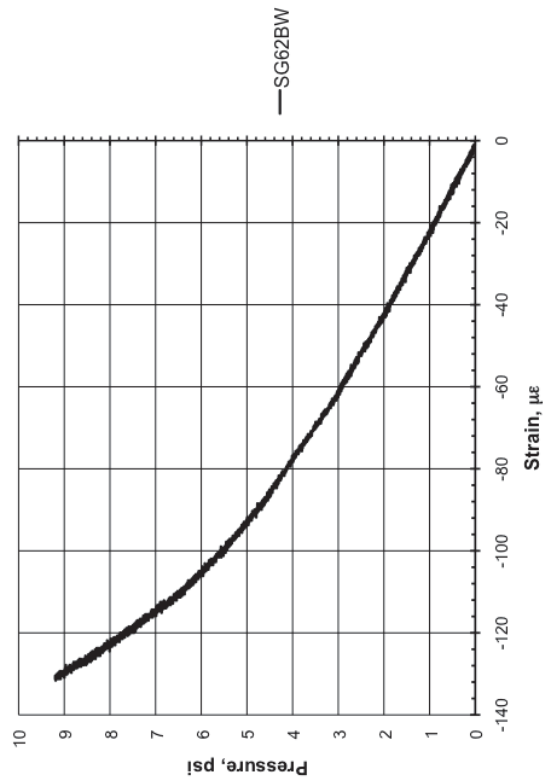


Figure C73. 1P test, strain gage SG62BW.

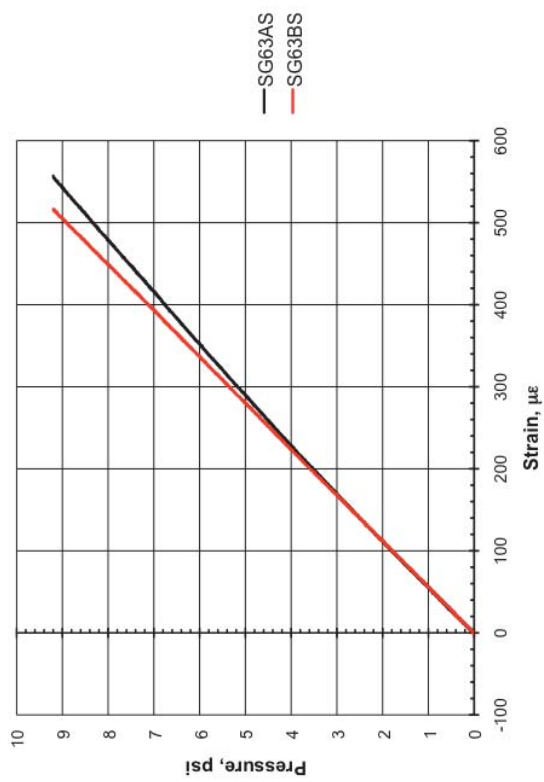


Figure C74. 1P test, strain gages SG63AS and SG63BS.

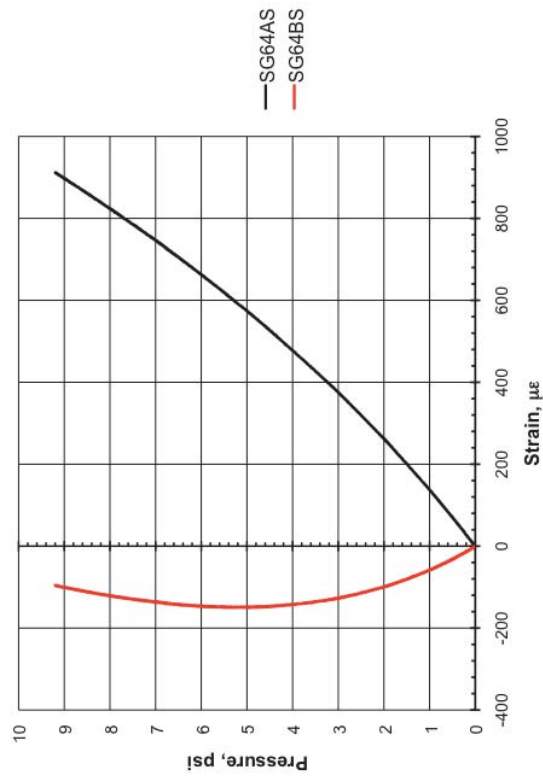


Figure C75. 1P test, strain gages SG64AS and SG64BS.

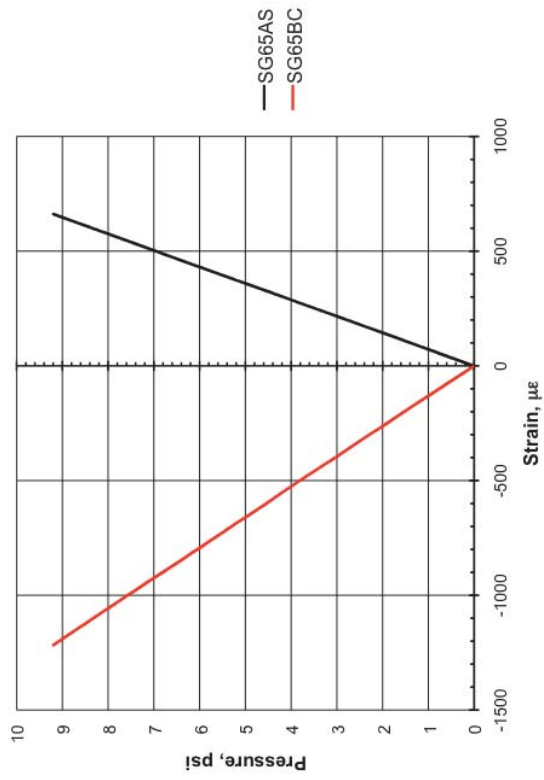


Figure C76. 1P test, strain gages SG65AS and SG65BC.



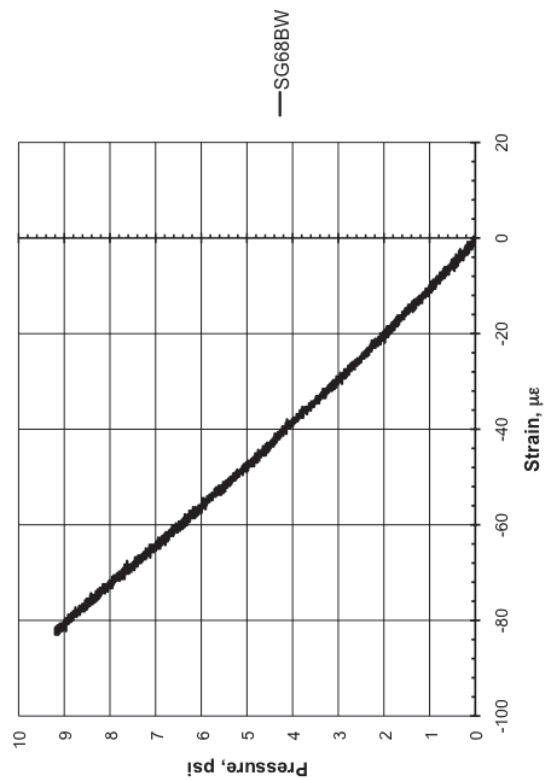


Figure C79. 1P test, strain gage SG68BW.

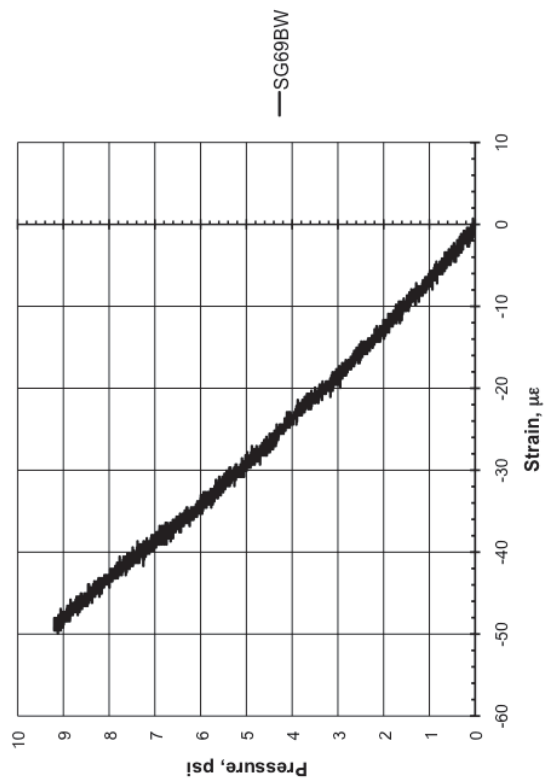


Figure C80. 1P test, strain gage SG69BW.

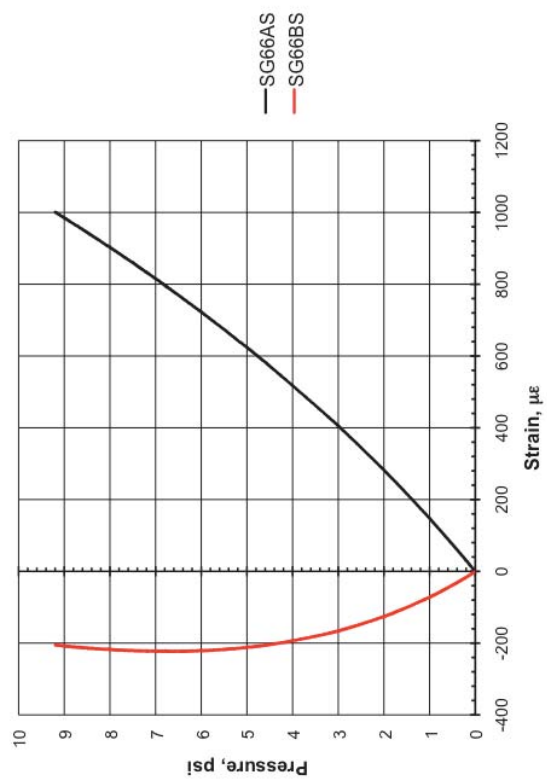


Figure C77. 1P test, strain gages SG66AS and SG66BS.

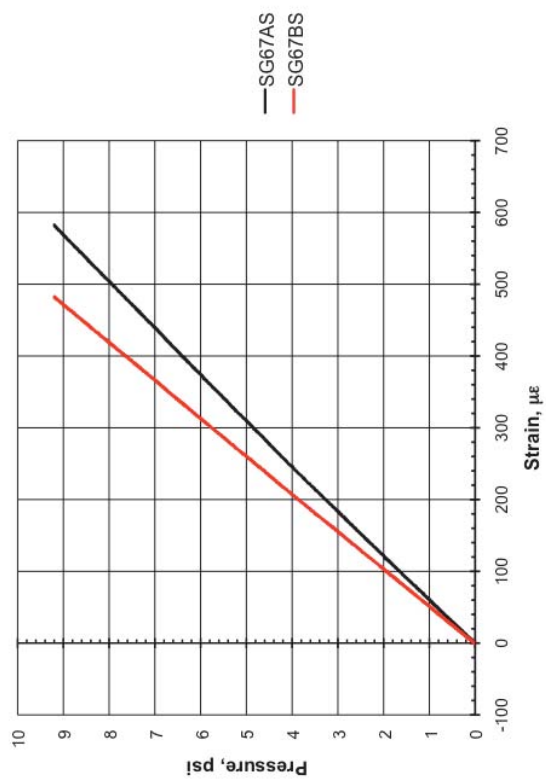


Figure C78. 1P test, strain gages SG67AS and SG67BS.

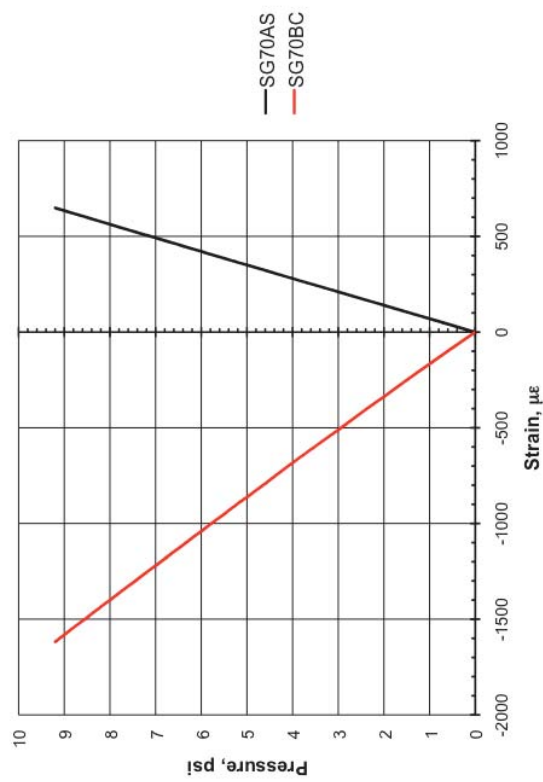


Figure C81. 1P test, strain gages SG70AS and SG70BC.

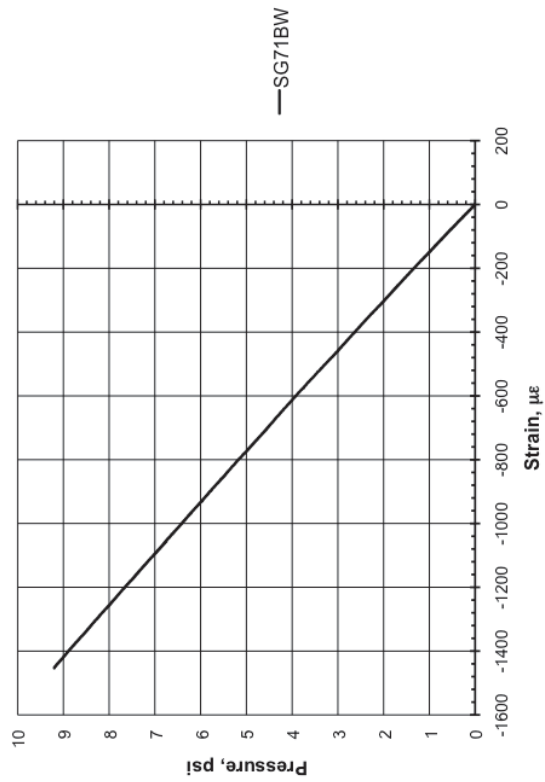


Figure C82. 1P test, strain gage SG71BW.

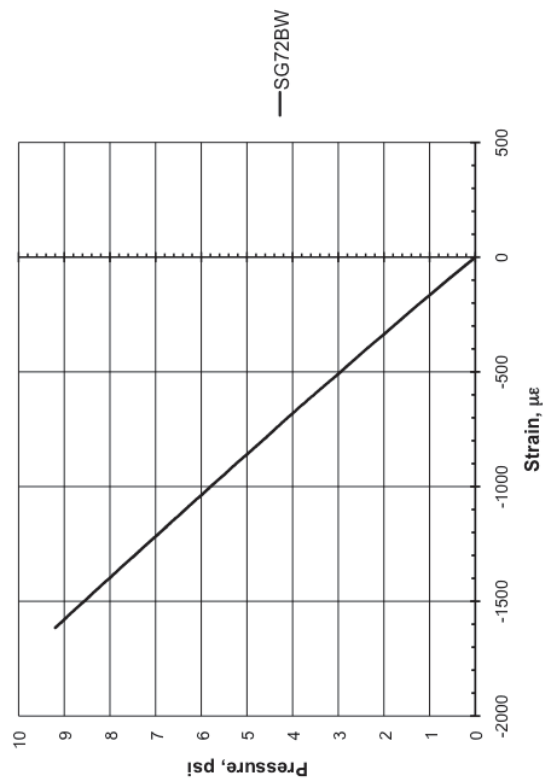


Figure C83. 1P test, strain gage SG72BW.

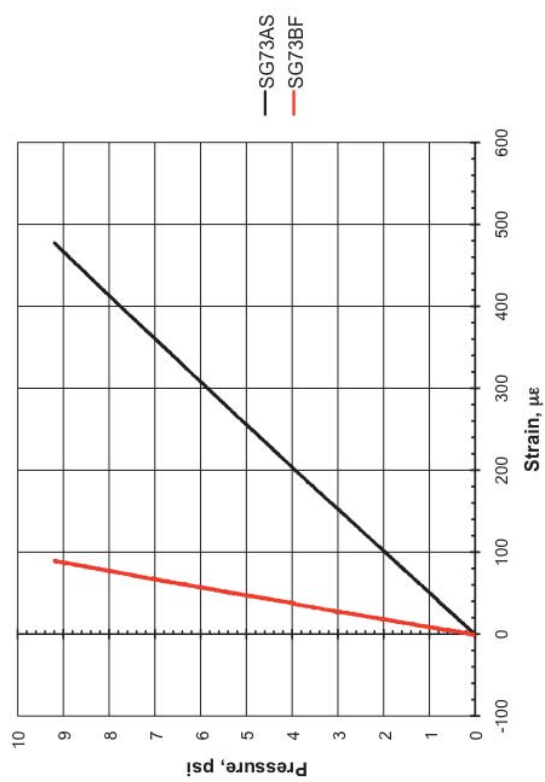


Figure C84. 1P test, strain gages SG73AS and SG73BF.

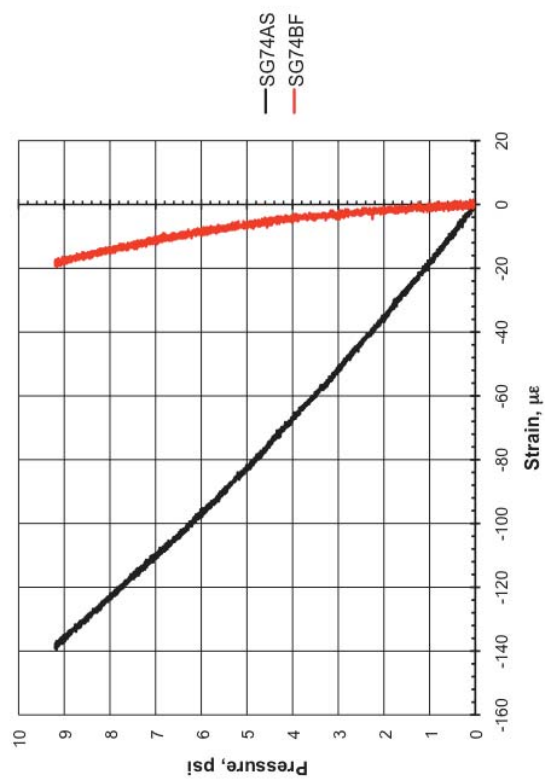


Figure C85. 1P test, strain gages SG74AS and SG74BF.

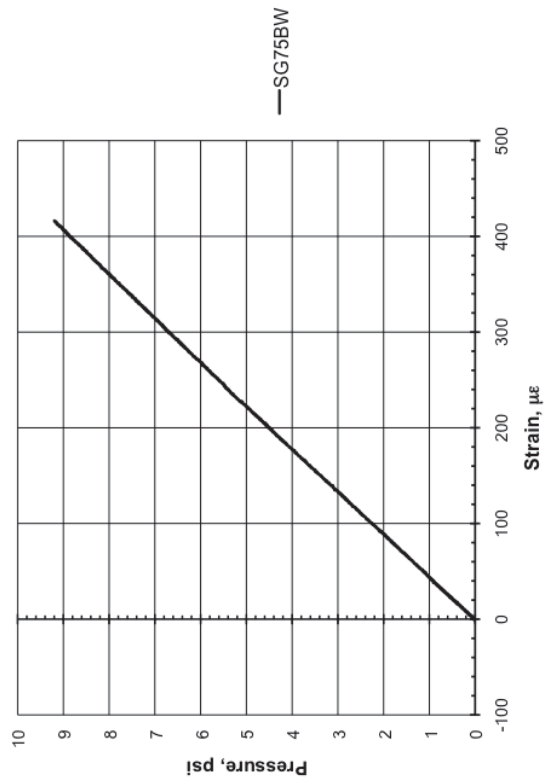


Figure C86. 1P test, strain gage SG75BW.

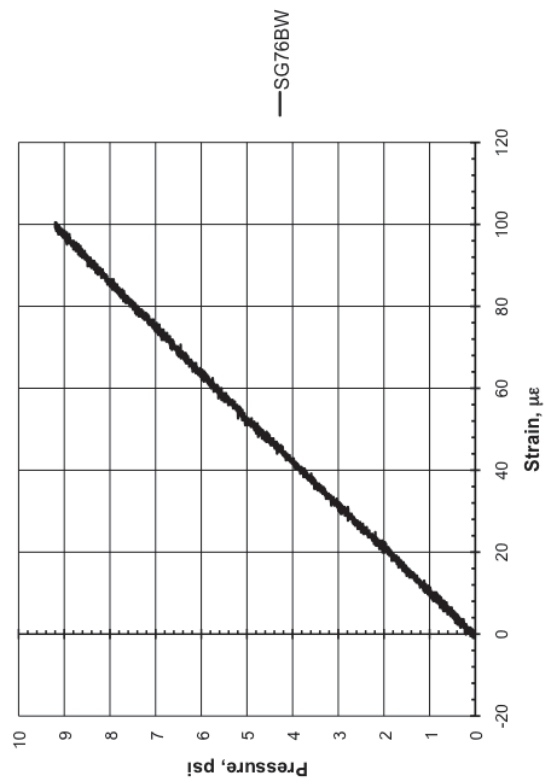


Figure C87. 1P test, strain gage SG76BW.

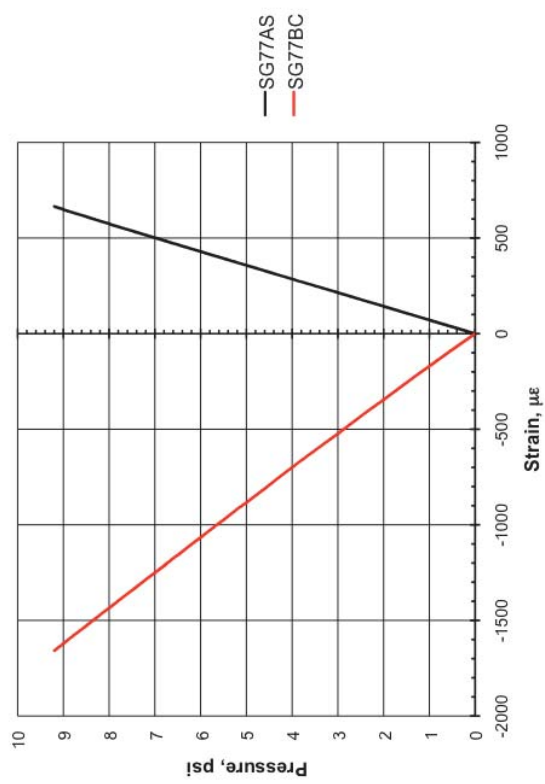


Figure C88. 1P test, strain gages SG77AS and SG77BC.

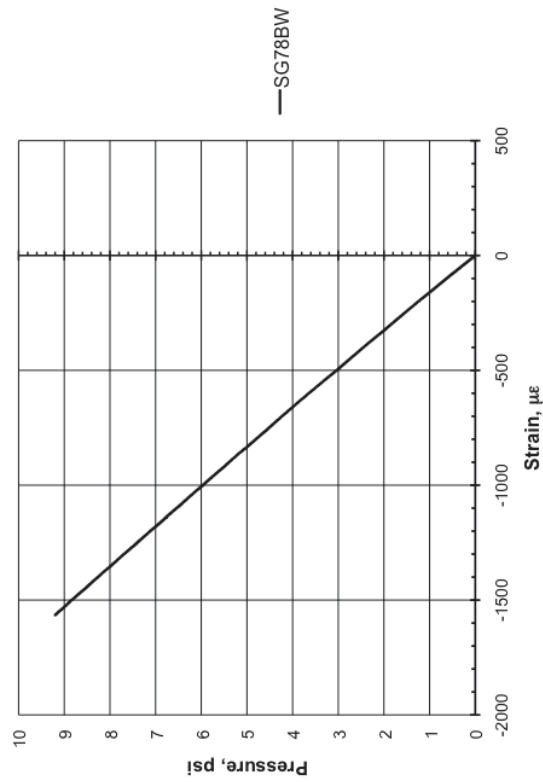


Figure C89. 1P test, strain gage SG78BW.

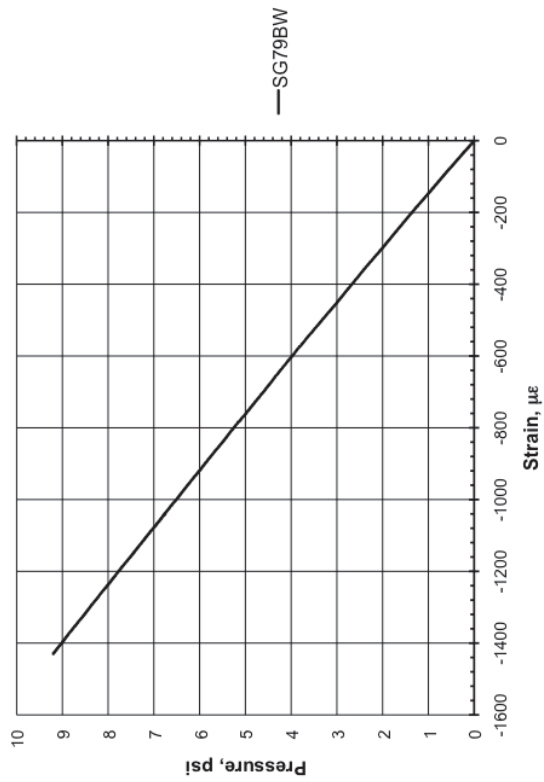


Figure C90. 1P test, strain gage SG70BW.

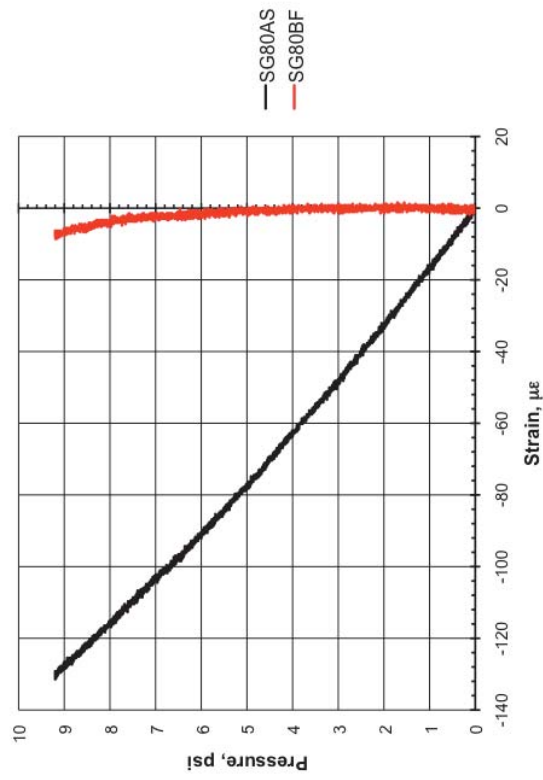


Figure C91. 1P test, strain gages SG80AS and SG80BF.

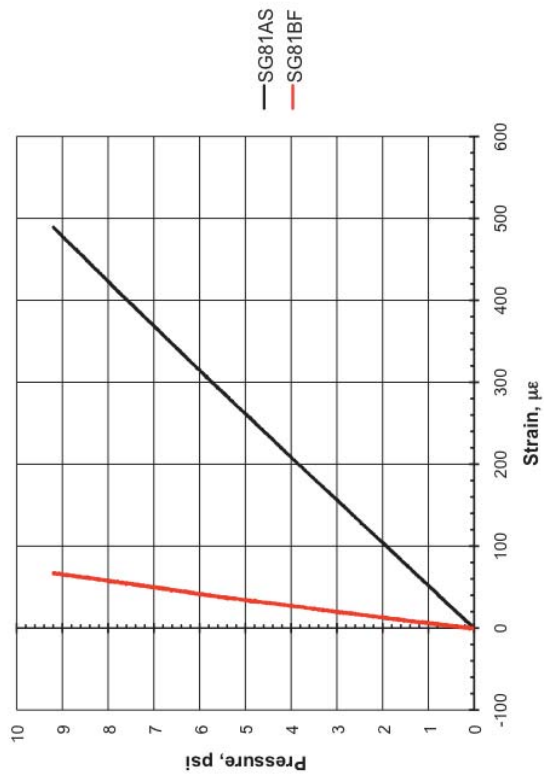


Figure C92. 1P test, strain gages SG81AS and SG81BF.

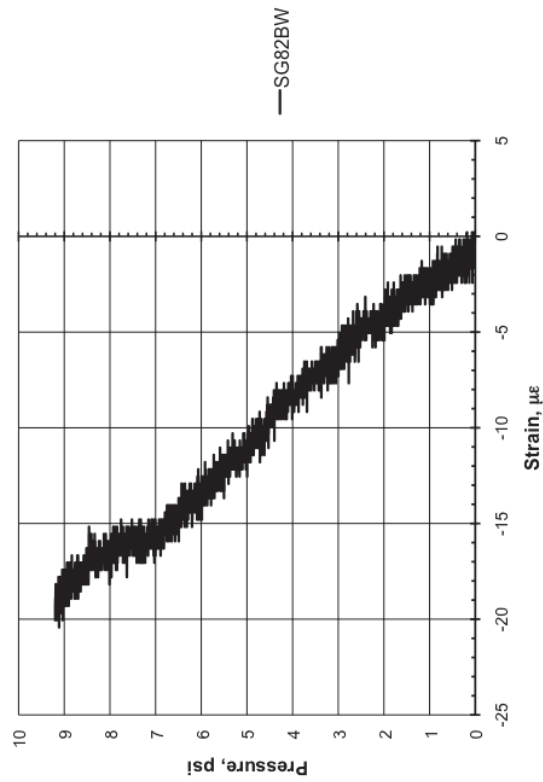


Figure C93. 1P test, strain gage SG82BW.

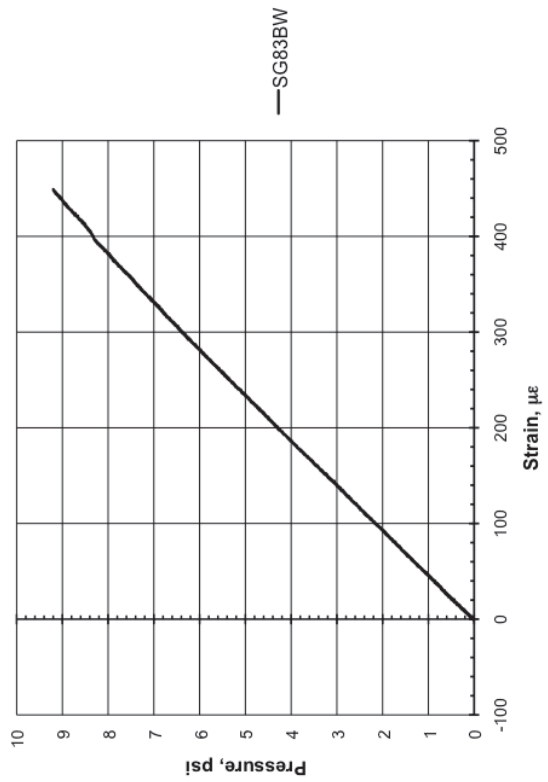


Figure C94. 1P test, strain gage SG83BW.

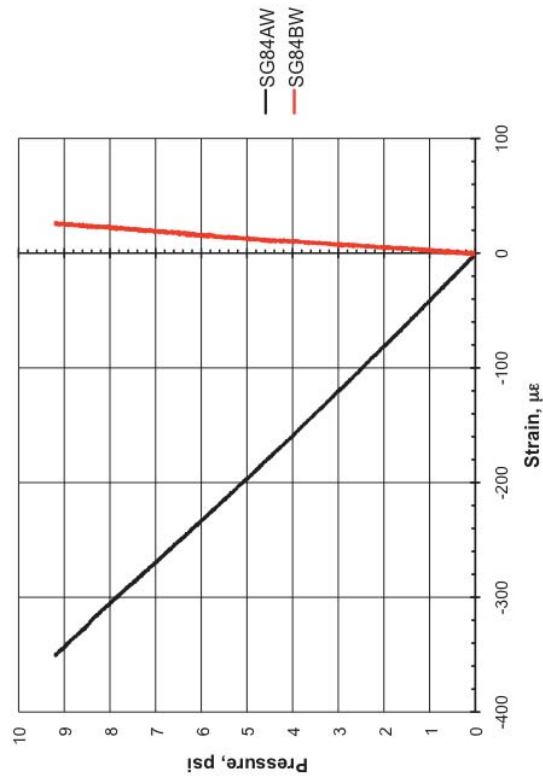


Figure C95. 1P test, strain gages SG84AW and SG84BW.

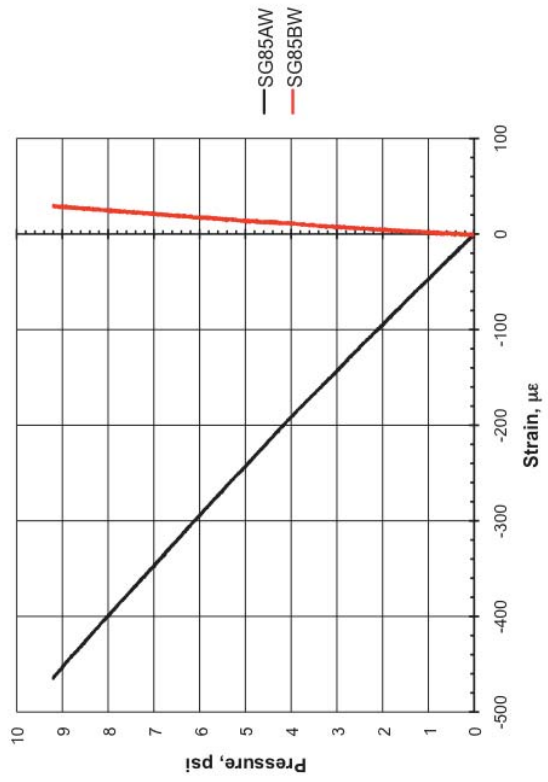


Figure C96. 1P test, strain gages SG85AW and SG85BW.

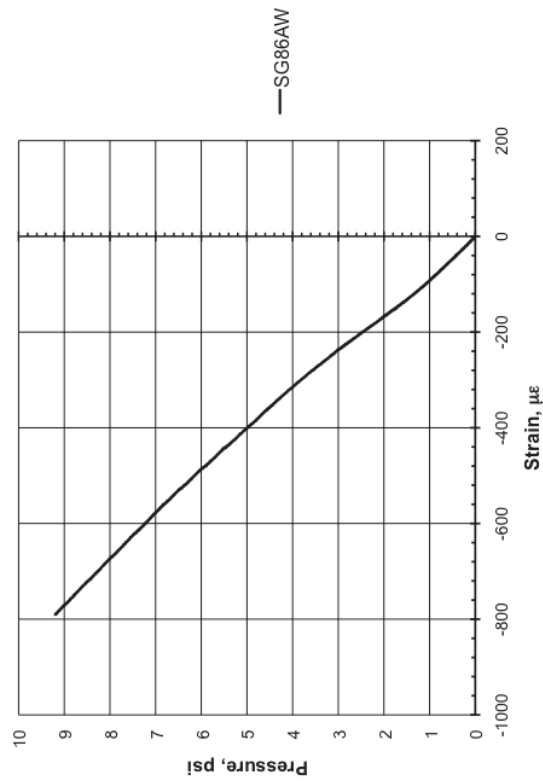


Figure C97. 1P test, strain gage SG86AW.

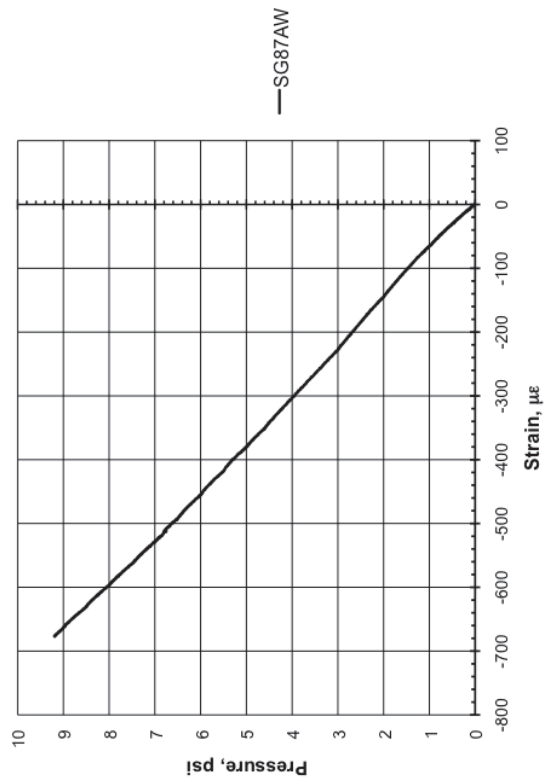


Figure C98. 1P test, strain gage SG87AW.

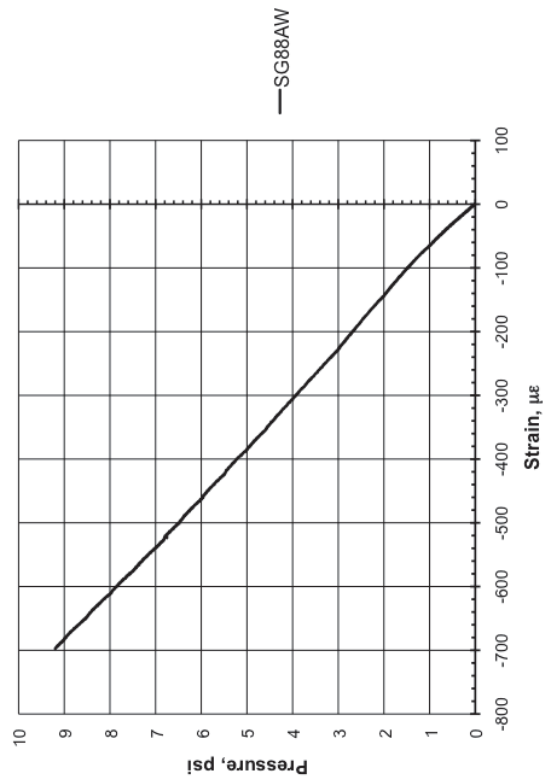


Figure C99. 1P test, strain gage SG88AW.

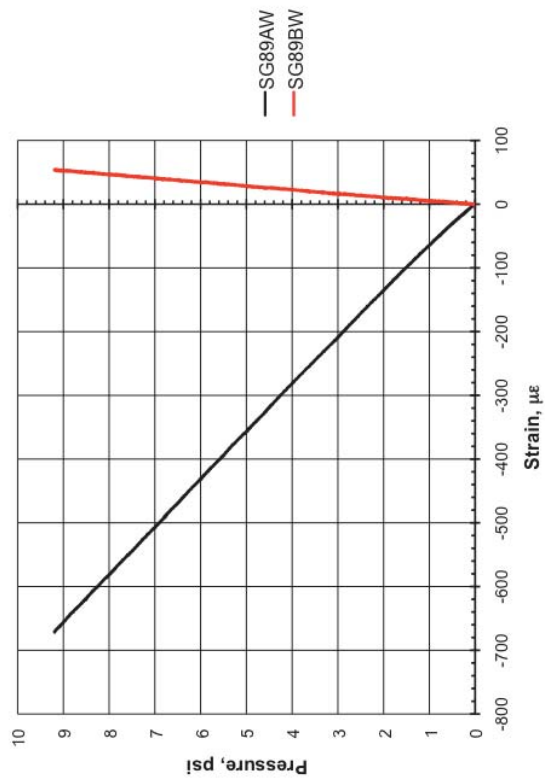


Figure C100. 1P test, strain gages SG89AW and SG89BW.

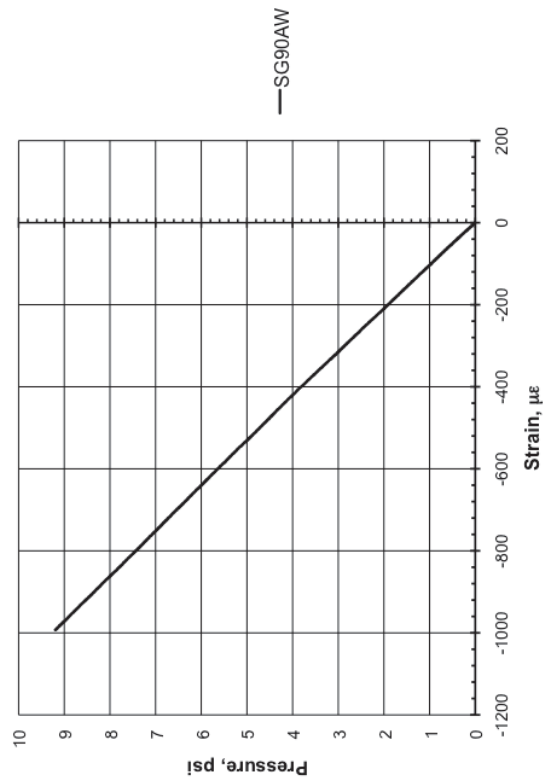


Figure C101. 1P test, strain gage SG90AW.

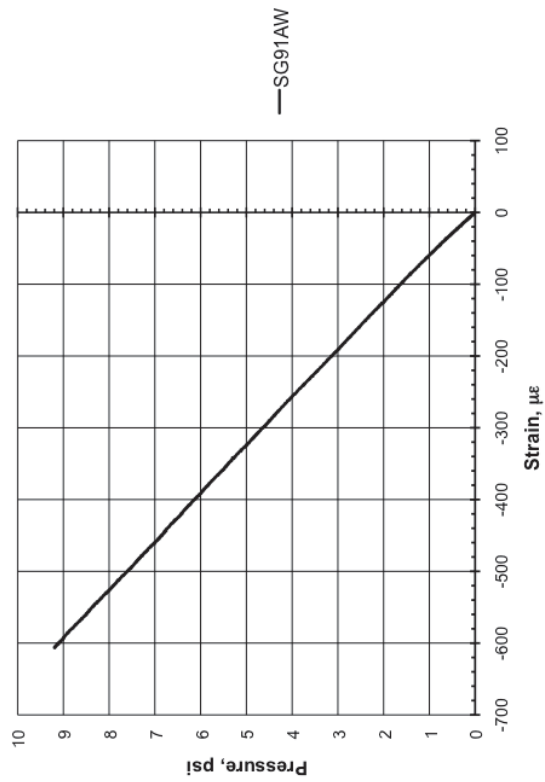


Figure C102. 1P test, strain gage SG91AW.

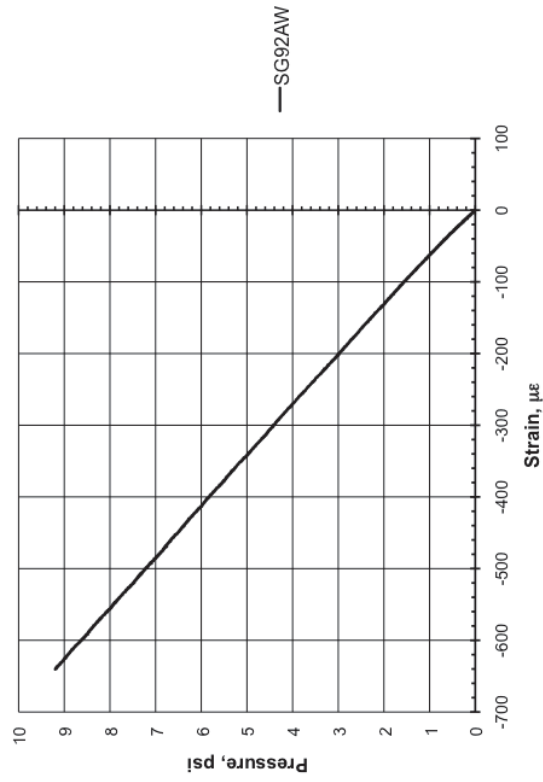


Figure C103. 1P test, strain gage SG92AW.

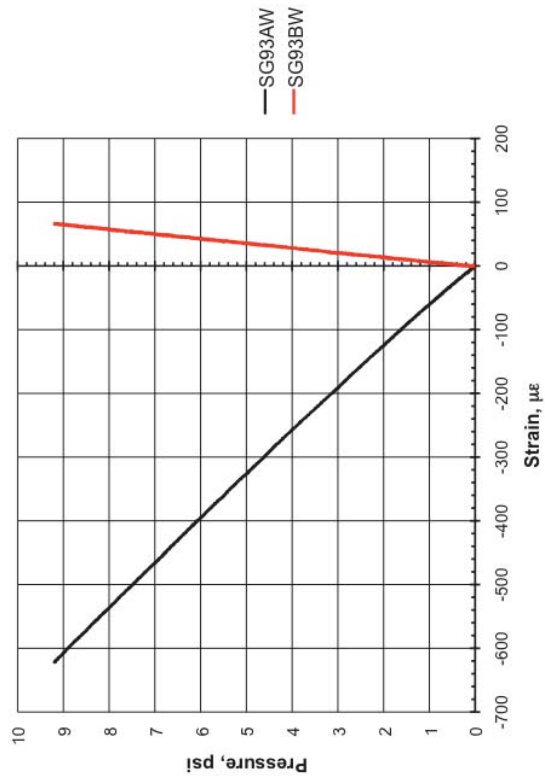


Figure C104. 1P test, strain gages SG93AW and SG93BW.

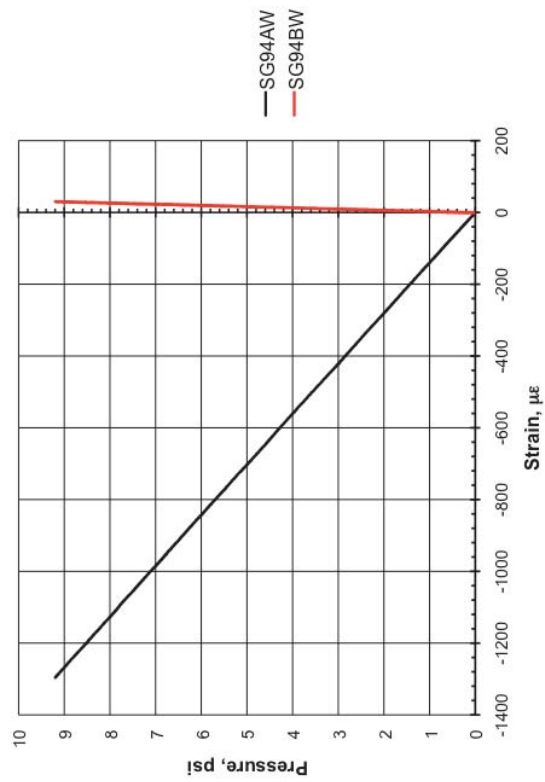


Figure C105. 1P test, strain gages SG94AW and SG94BW.

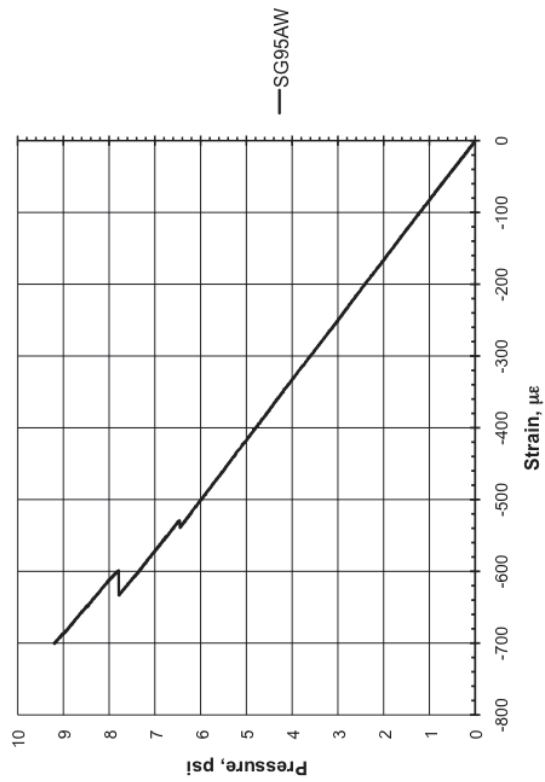


Figure C106. 1P test, strain gage SG95AW.

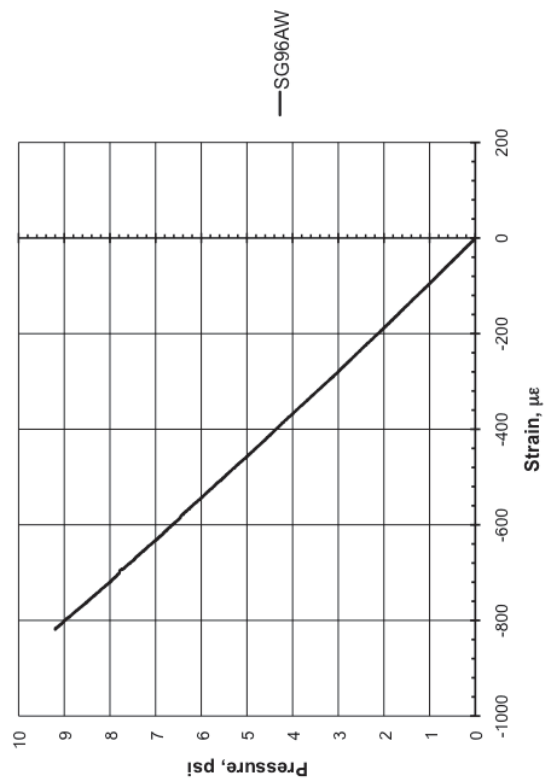


Figure C107. 1P test, strain gage SG96AW.

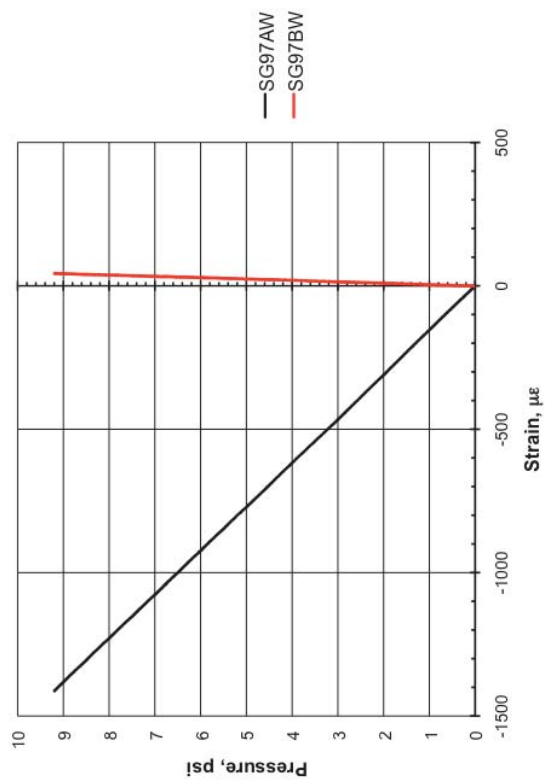


Figure C108. 1P test, strain gages SG97AW and SG97BW.



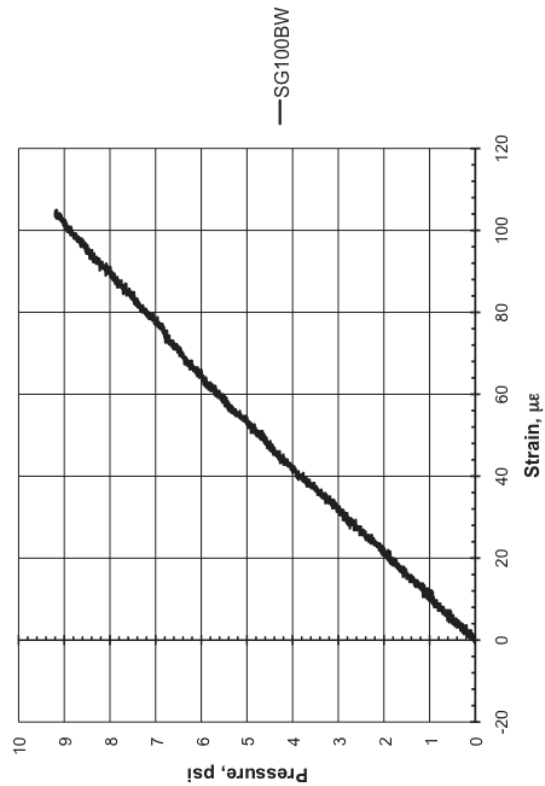


Figure C111. 1P test, strain gage SG100BW.

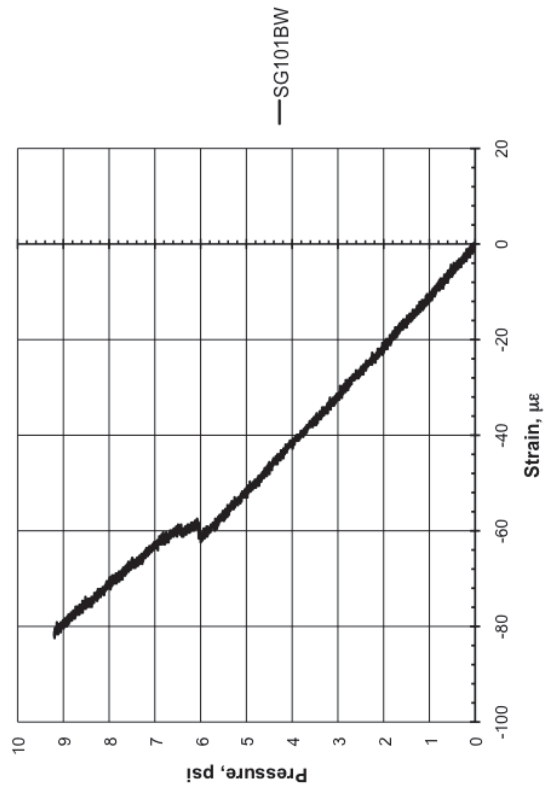


Figure C112. 1P test, strain gage SG101BW.

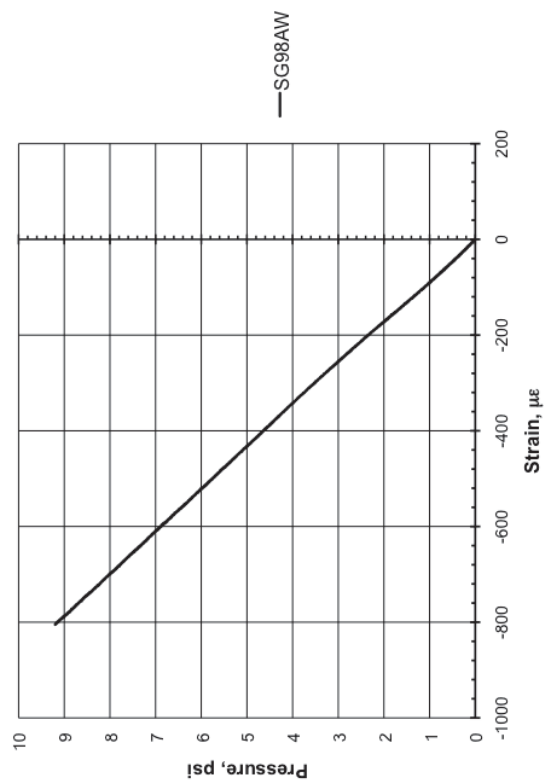


Figure C109. 1P test, strain gage SG98AW.

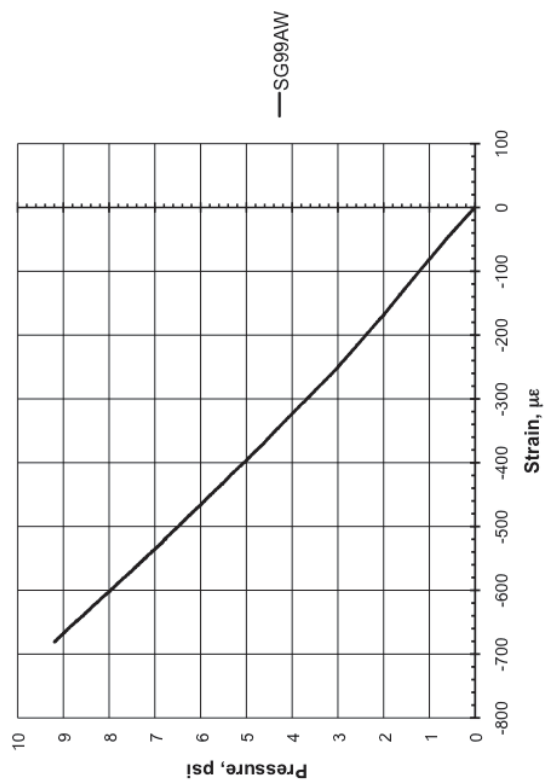


Figure C110. 1P test, strain gage SG99AW.

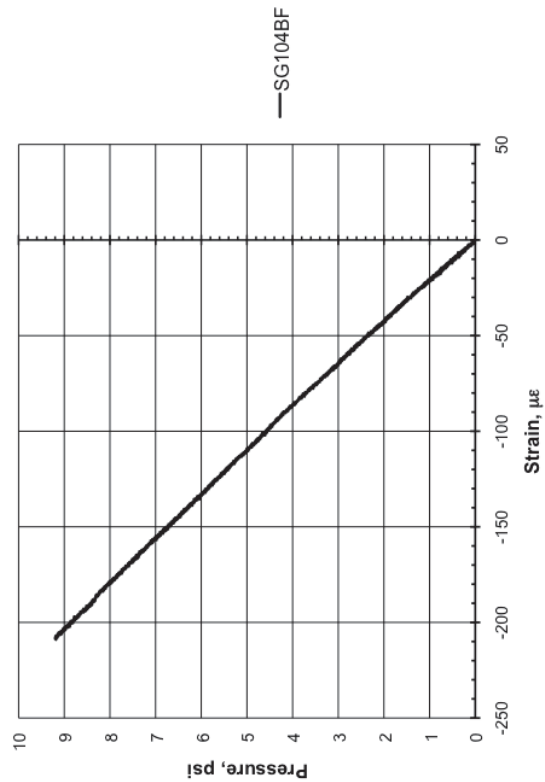


Figure C115. 1P test, strain gage SG104BF.

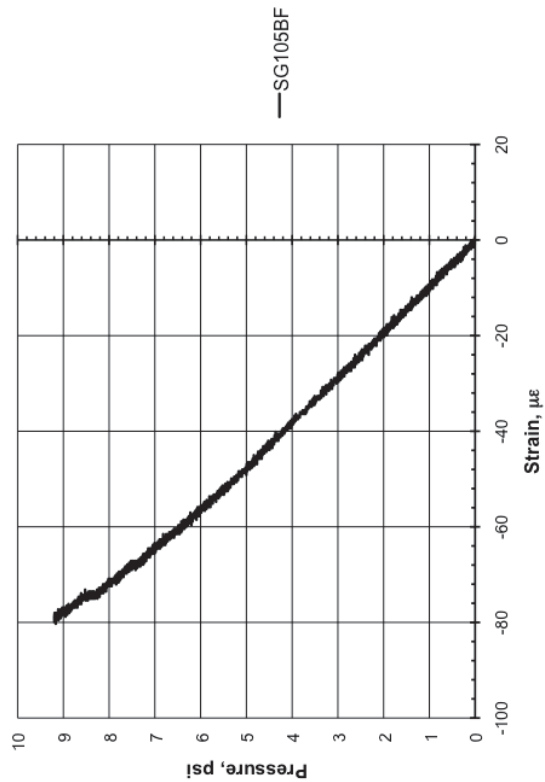


Figure C116. 1P test, strain gage SG105BF.

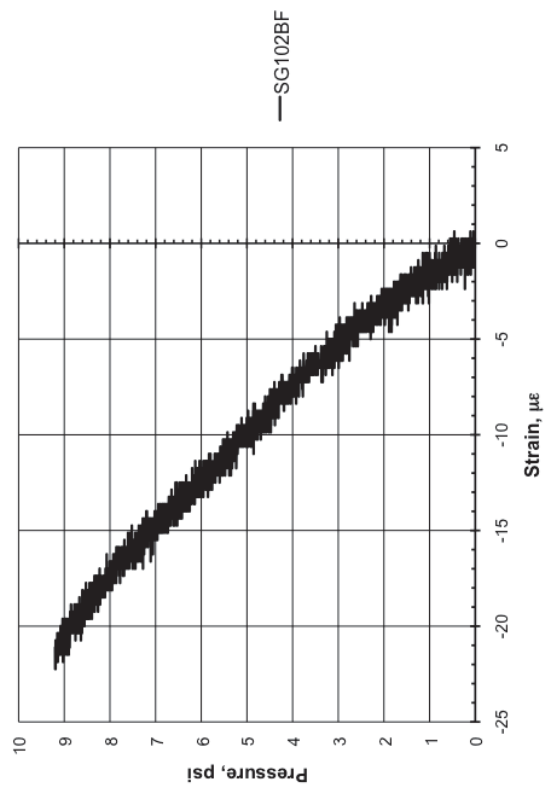


Figure C113. 1P test, strain gage SG102BF.

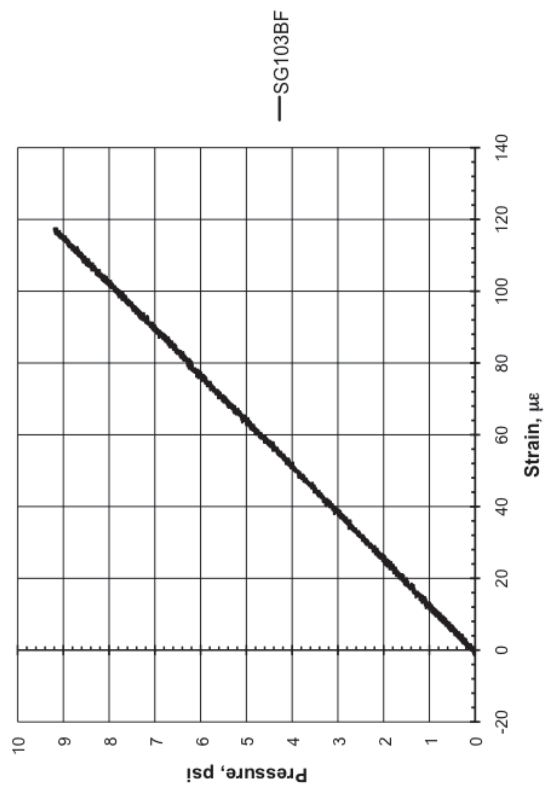


Figure C114. 1P test, strain gage SG103BF.

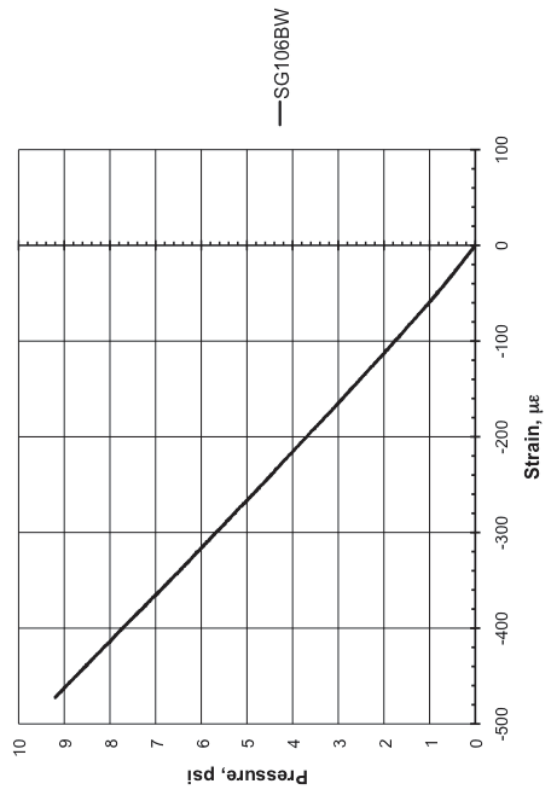


Figure C117. 1P test, strain gage SG106BW.

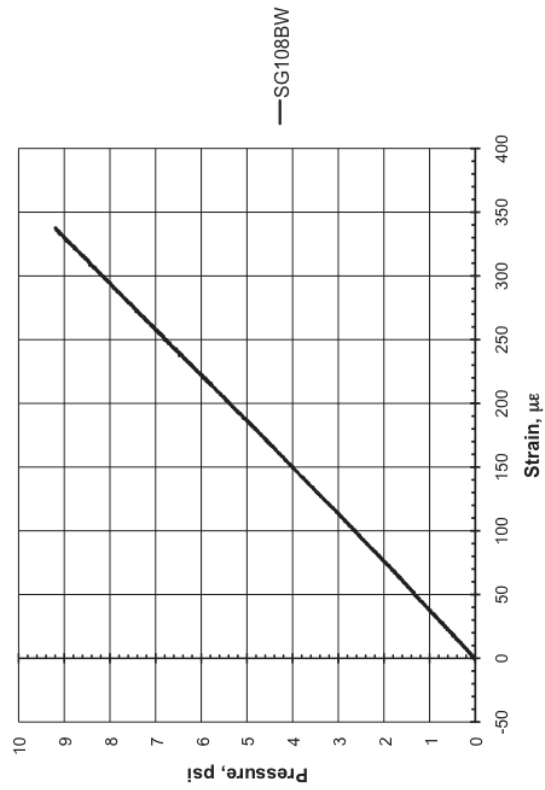


Figure C119. 1P test, strain gage SG108BW.

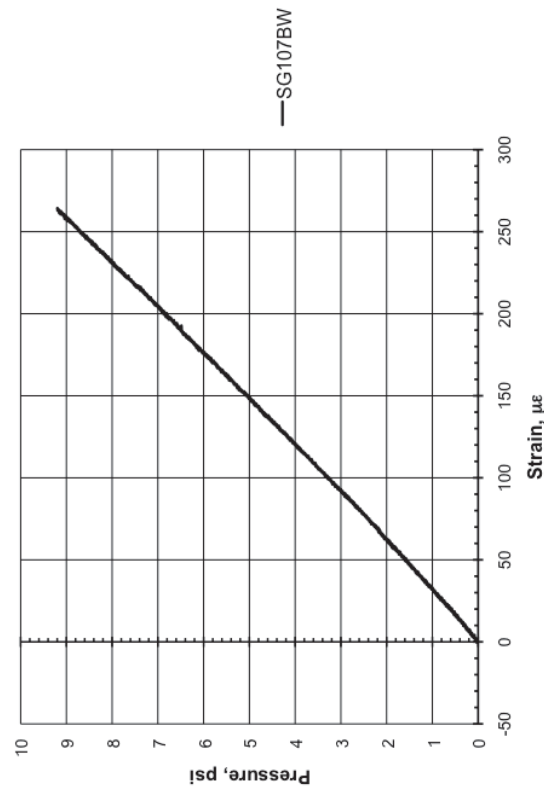


Figure C118. 1P test, strain gage SG107BW.

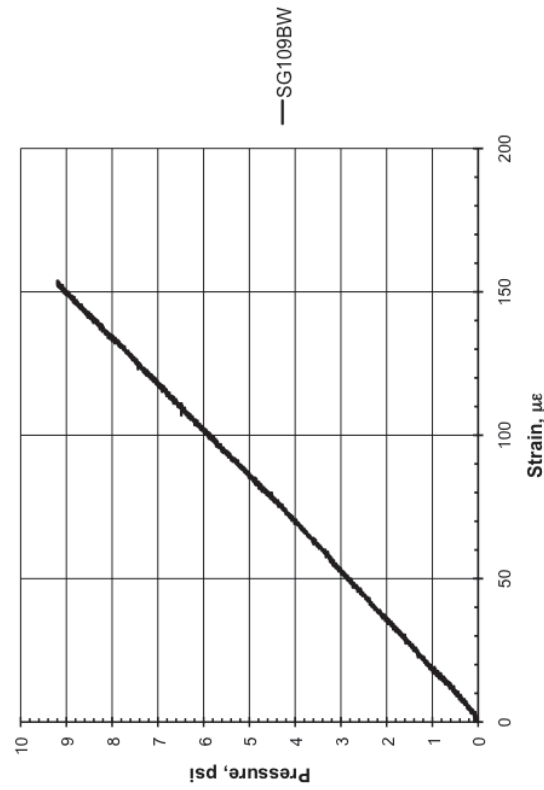


Figure C120. 1P test, strain gage SG109BW.

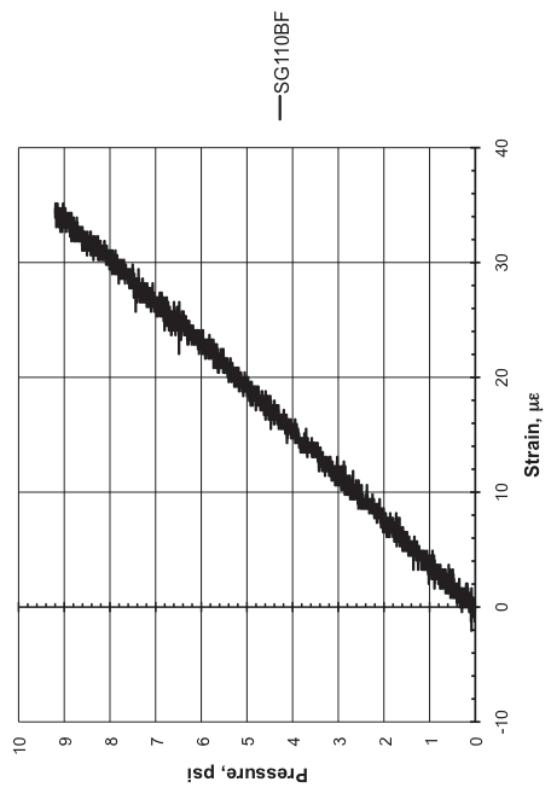


Figure C121. 1P test, strain gage SG110BF.

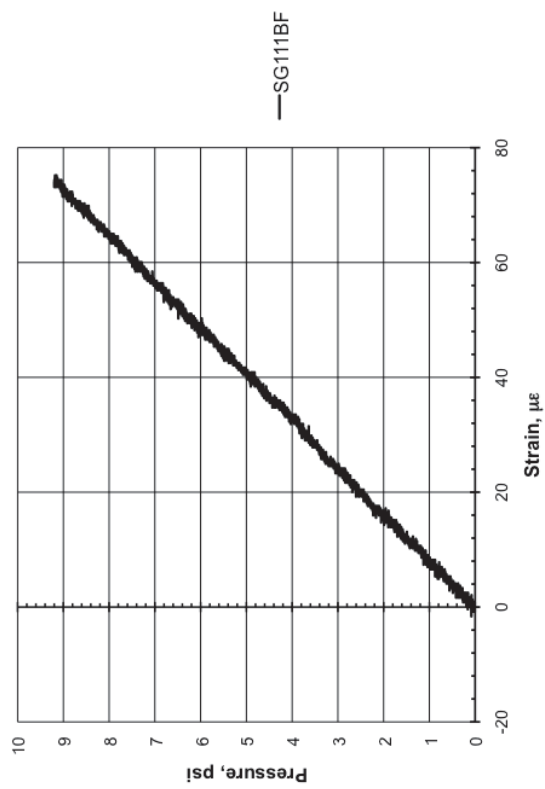


Figure C122. 1P test, strain gage SG111BF.

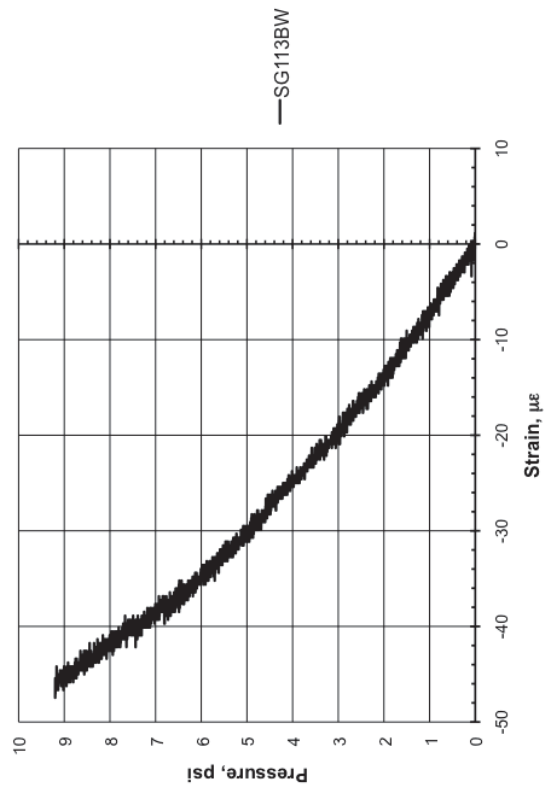


Figure C123. 1P test, strain gage SG113BW.

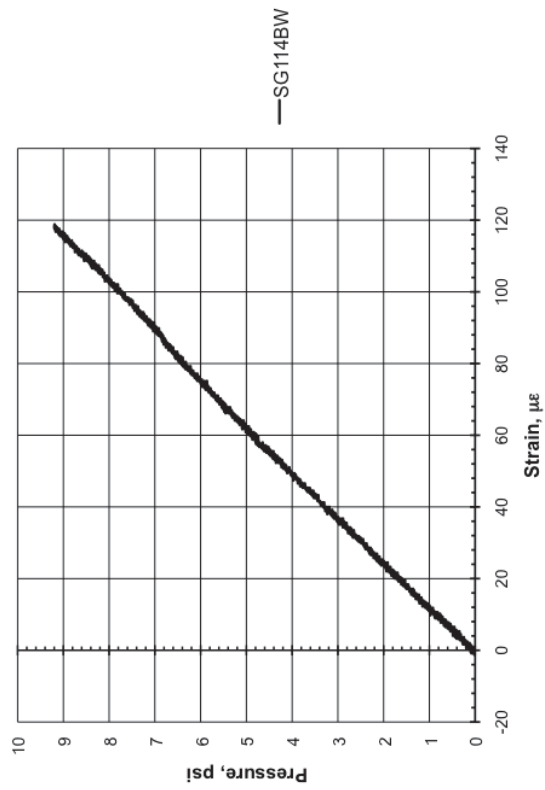


Figure C124. 1P test, strain gage SG114BW.

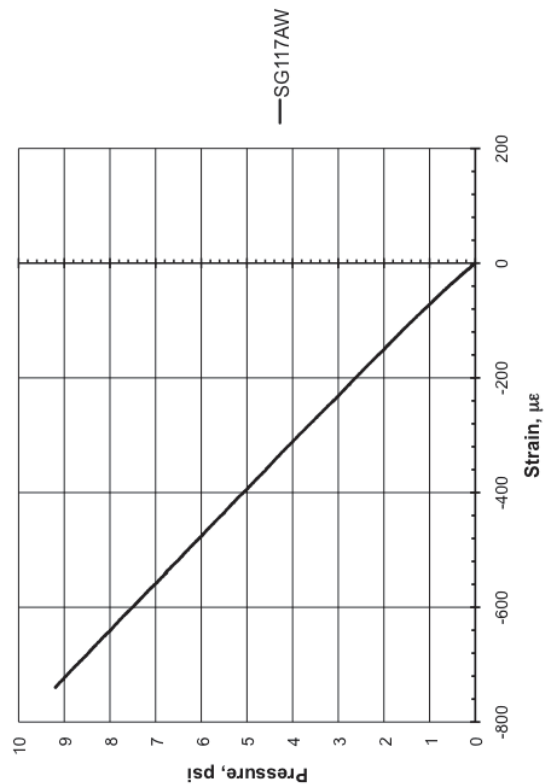


Figure C127. 1P test, strain gage SG117AW.

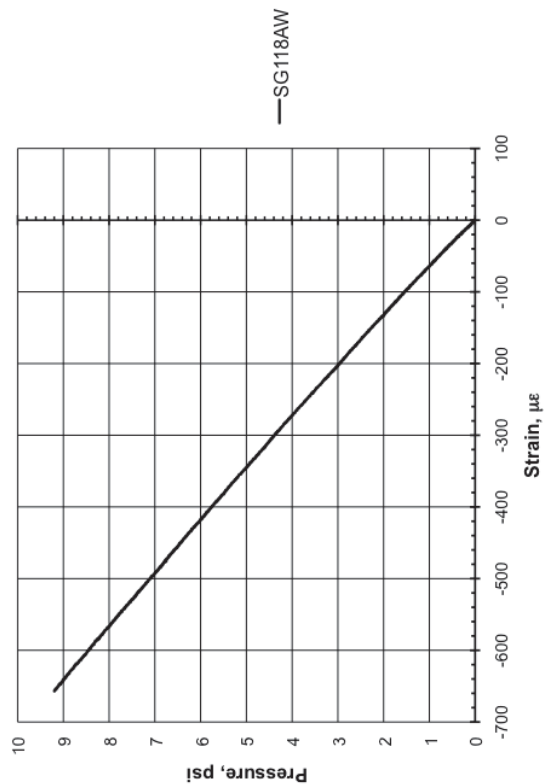


Figure C128. 1P test, strain gage SG118AW.

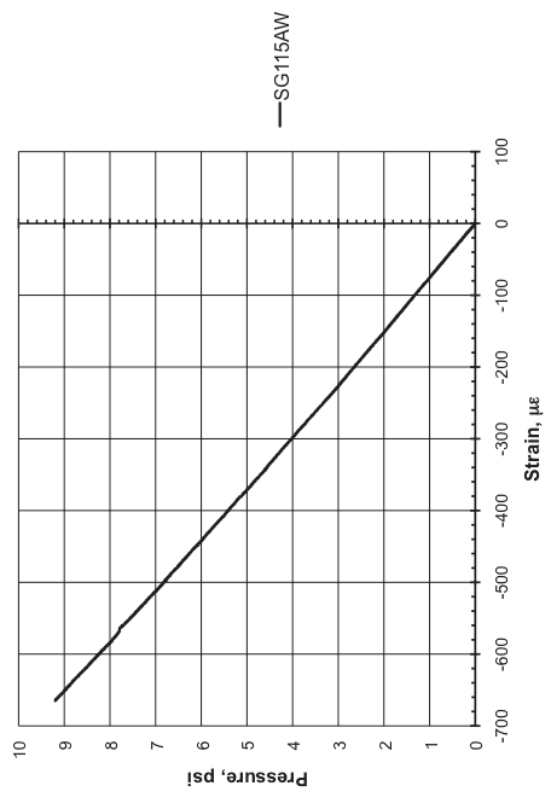


Figure C125. 1P test, strain gage SG115AW.

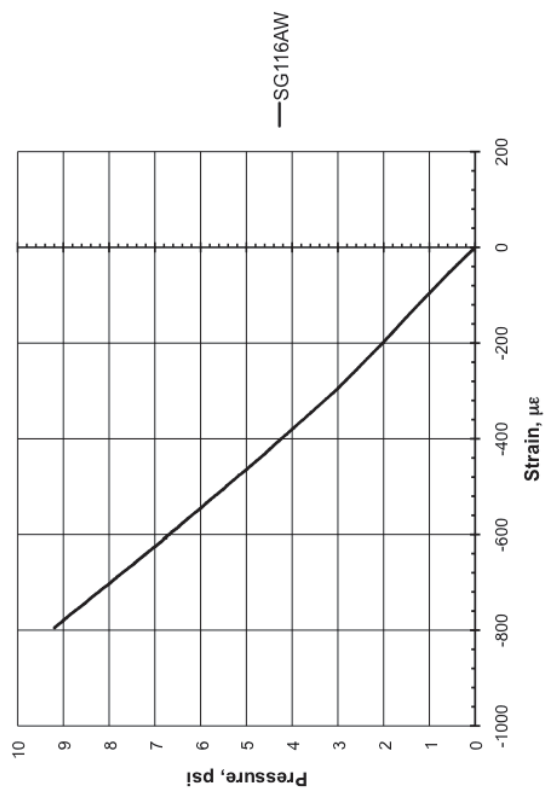
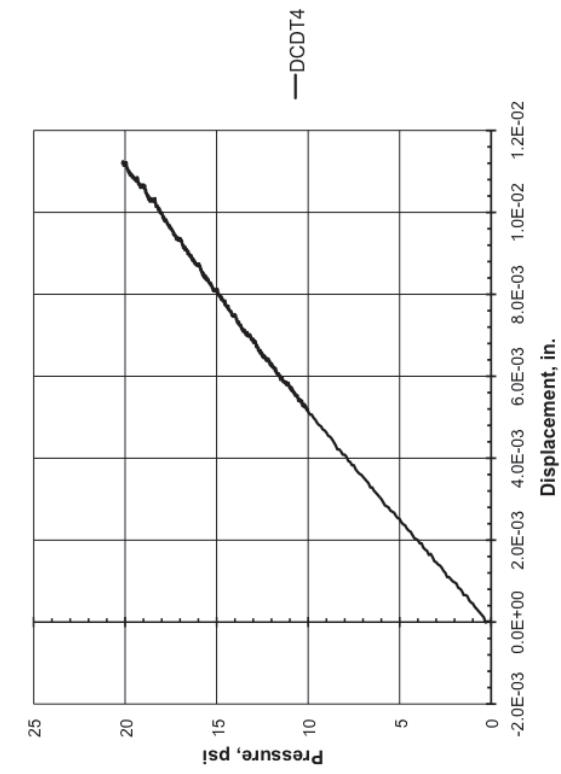
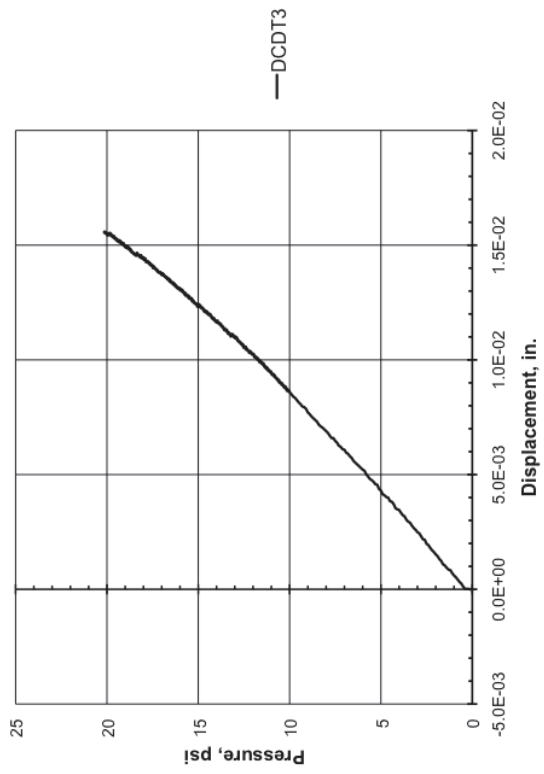
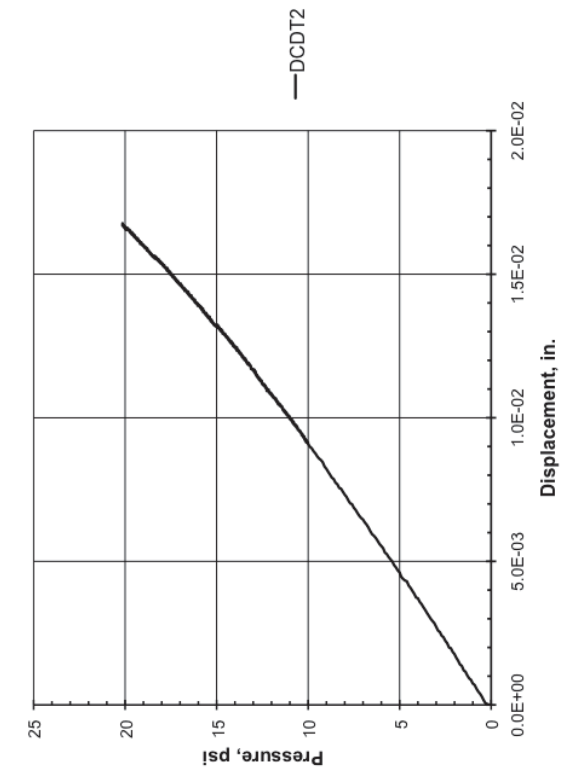
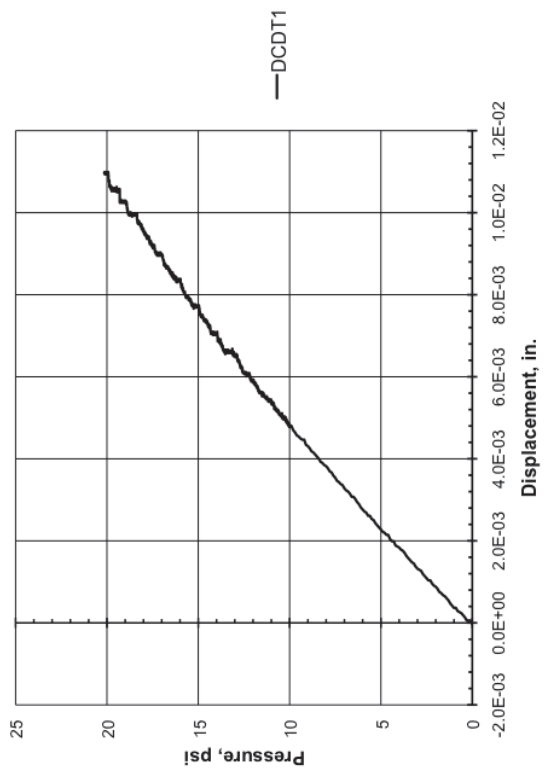
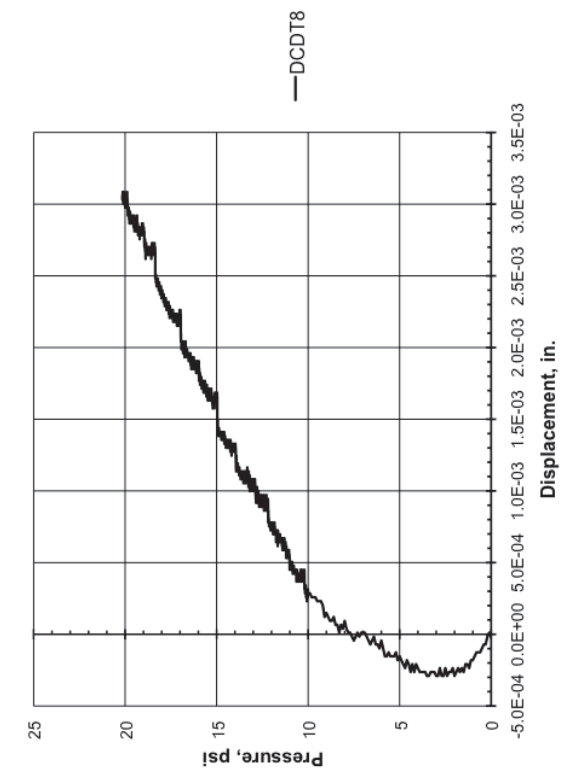
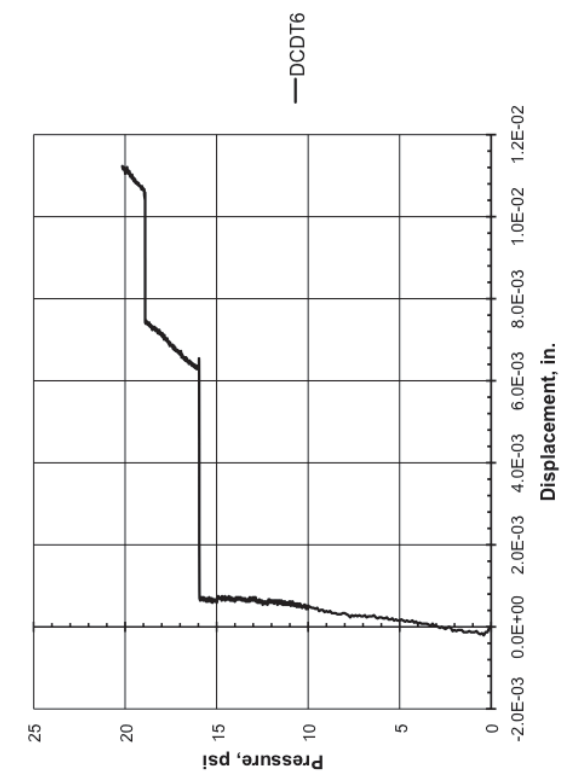
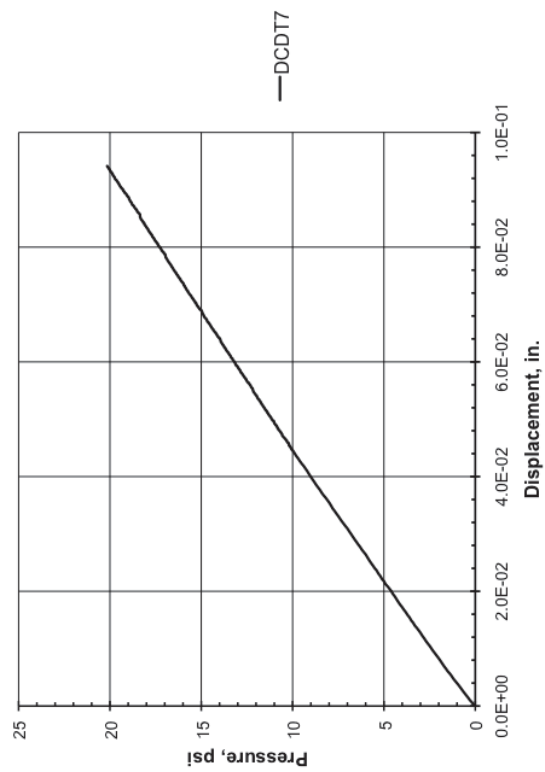
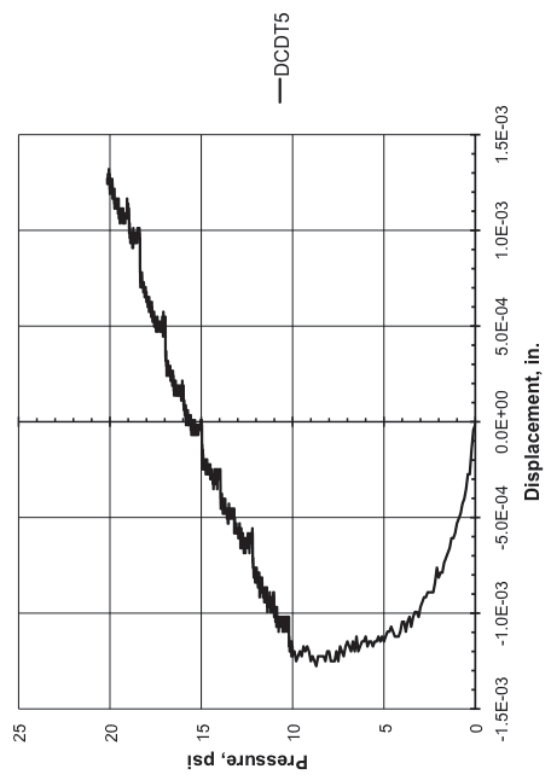


Figure C126. 1P test, strain gage SG116AW.

## **Appendix D:**

### **2.2P Test DCDT and Strain Gage Plots**







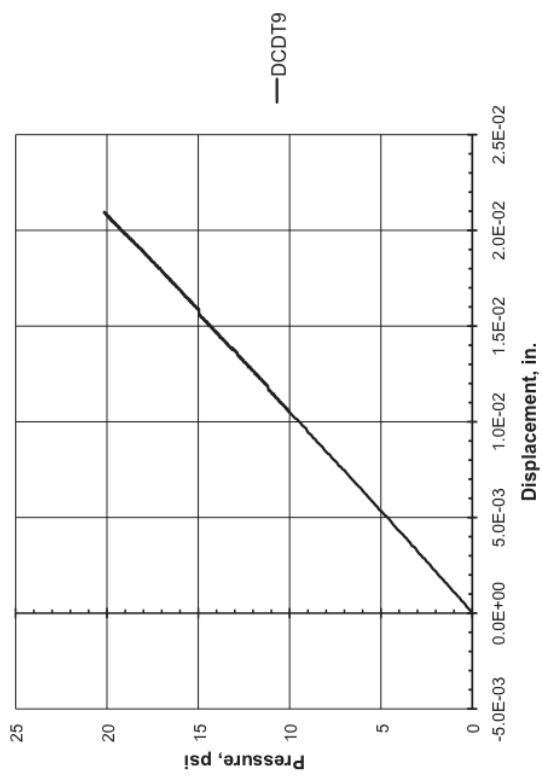


Figure D9. 2.2P test, DCDT9.

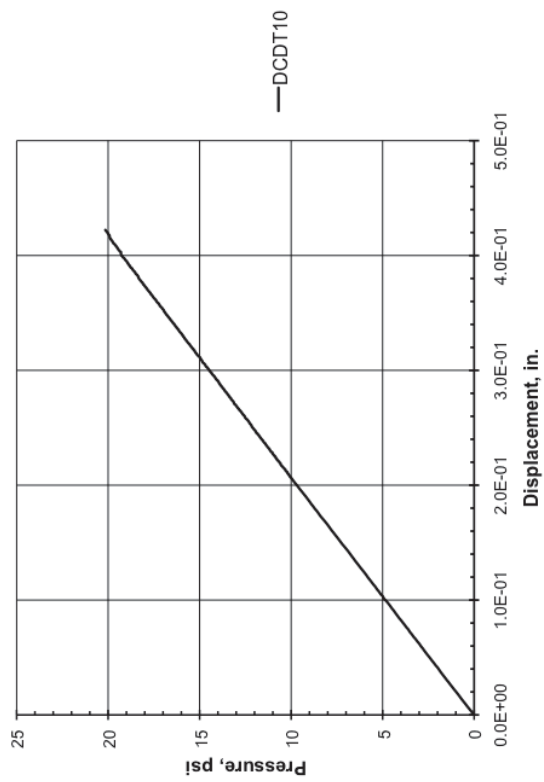


Figure D10. 2.2P test, DCDT10.

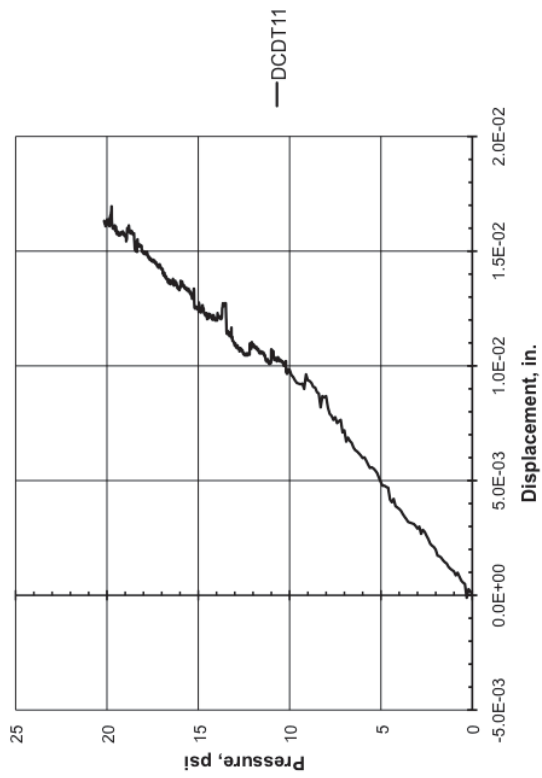


Figure D11. 2.2P test, DCDT11.

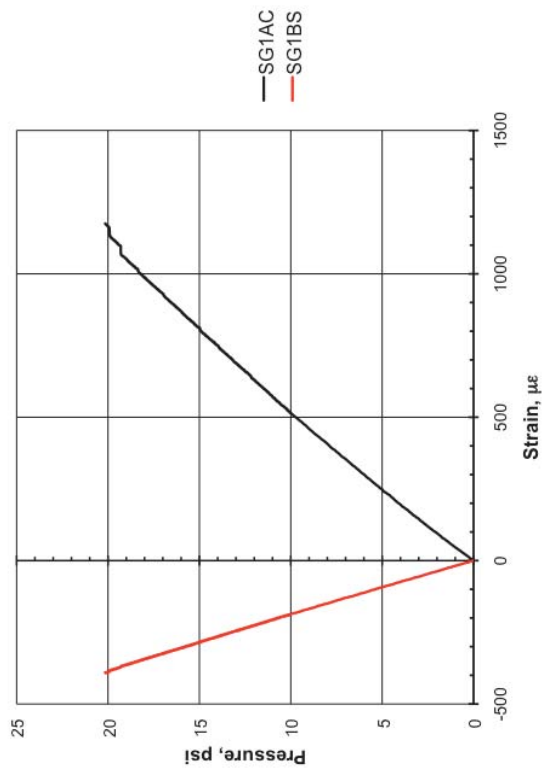


Figure D12. 2.2P test, strain gages SG1AC and SG1BS.

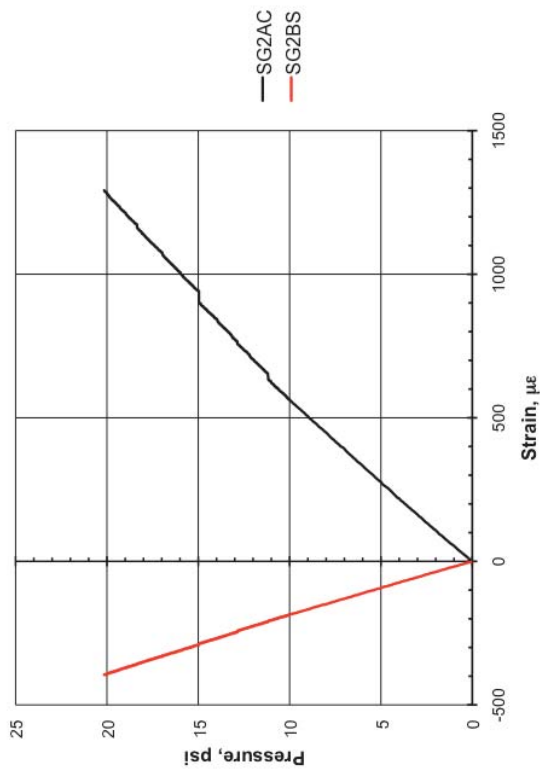


Figure D13. 2.2P test, strain gages SG2AC and SG2BS.

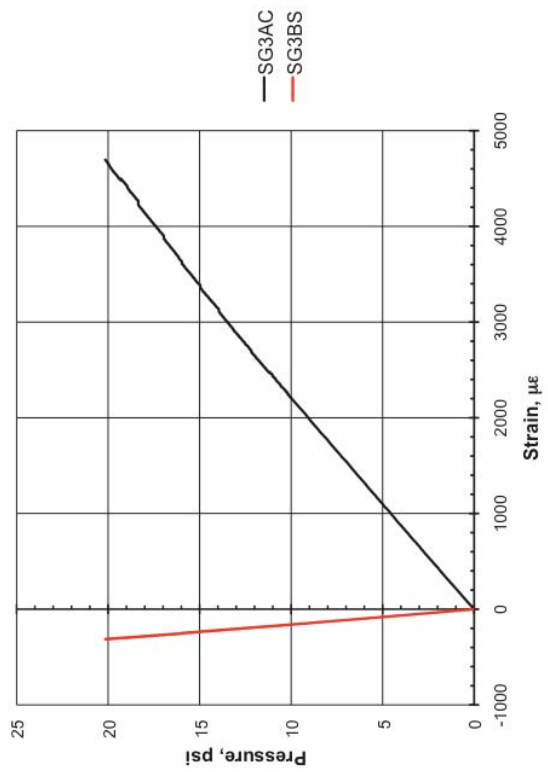


Figure D14. 2.2P test, strain gages SG3AC and SG3BS.

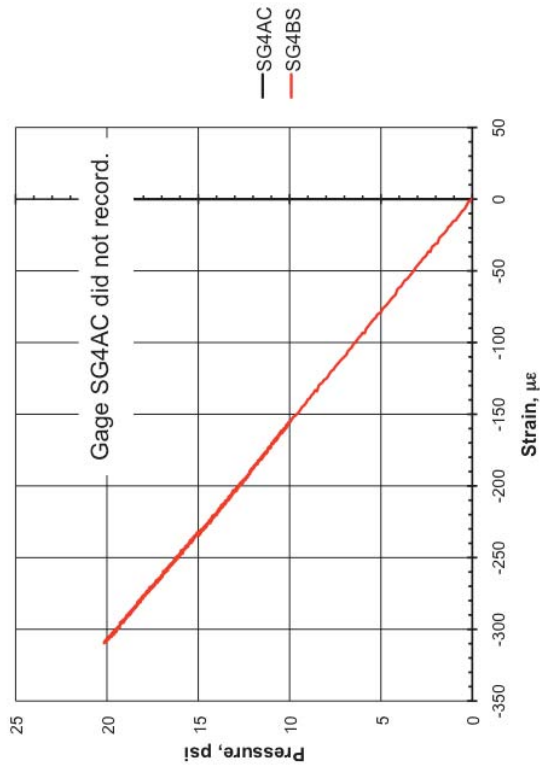


Figure D15. 2.2P test, strain gages SG4AC and SG4BS.

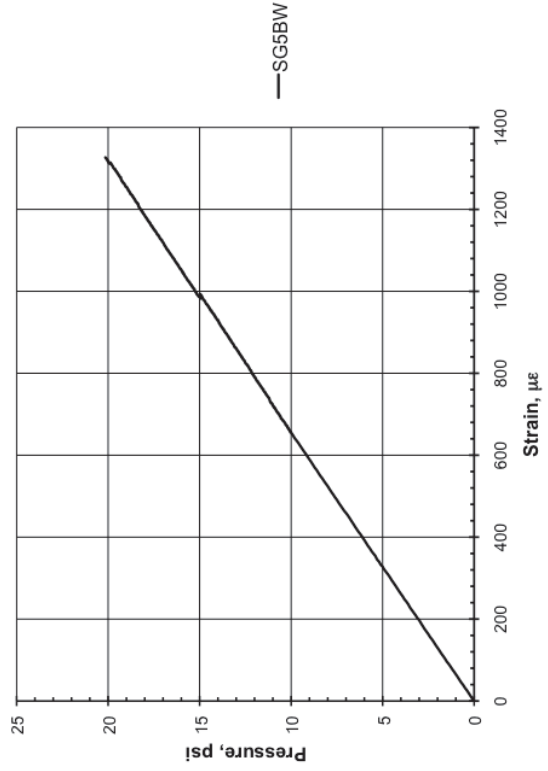


Figure D16. 2.2P test, strain gage SG5BW.

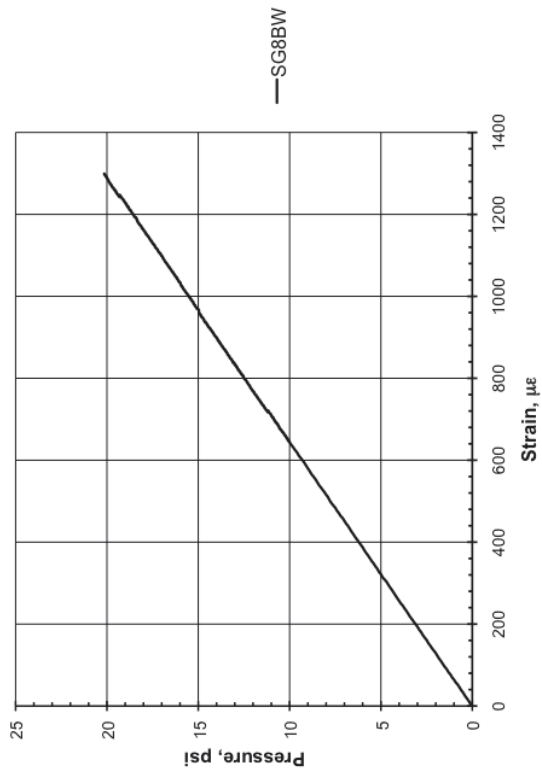


Figure D19. 2.2P test, strain gage SG8BW.

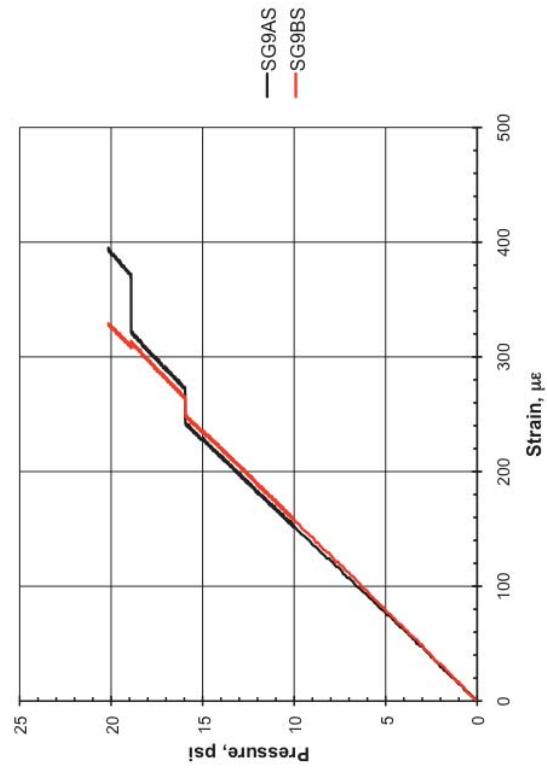


Figure D20. 2.2P test, strain gages SG9AS and SG9BS.

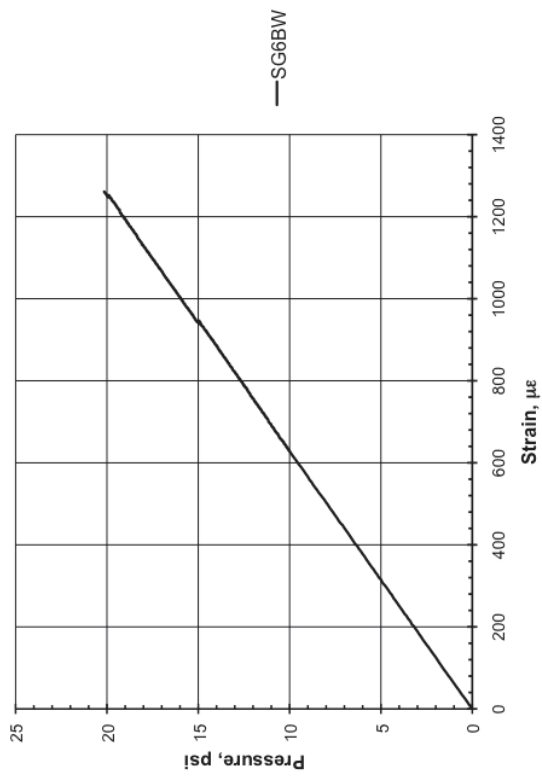


Figure D17. 2.2P test, strain gage SG6BW.

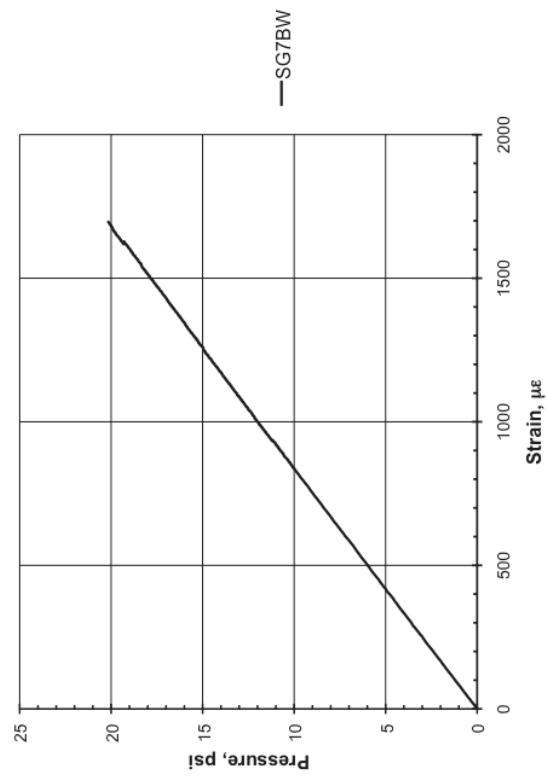


Figure D18. 2.2P test, strain gage SG7BW.

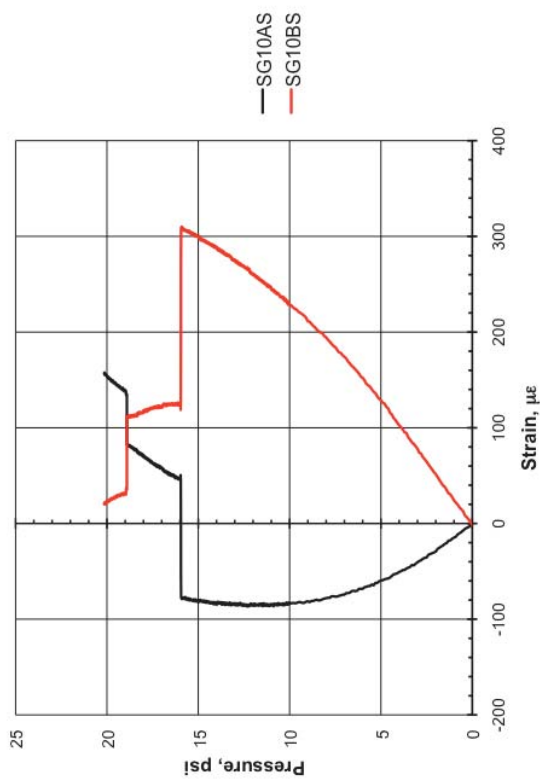


Figure D21. 2.2P test, strain gages SG10AS and SG10BS.

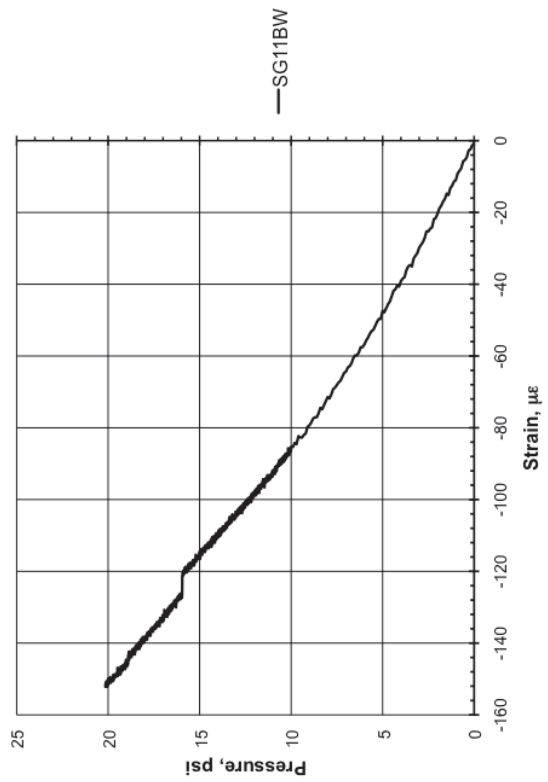


Figure D22. 2.2P test, strain gage SG11BW.

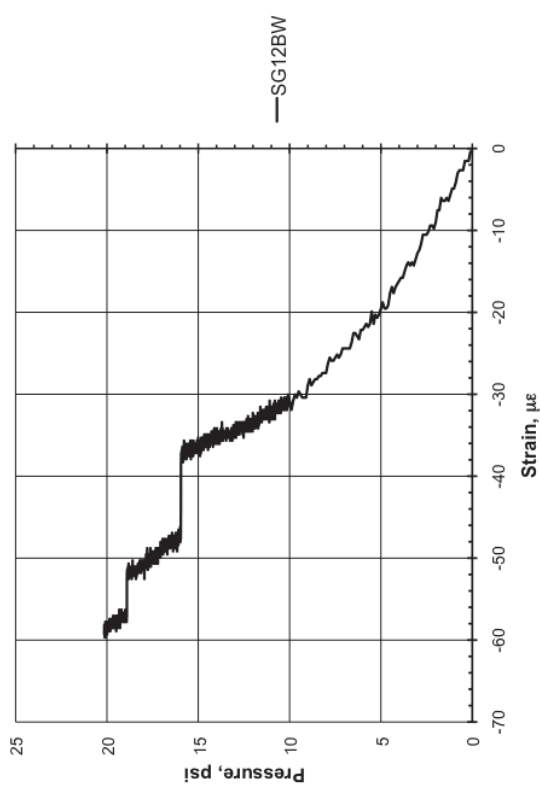


Figure D23. 2.2P test, strain gage SG12BW.

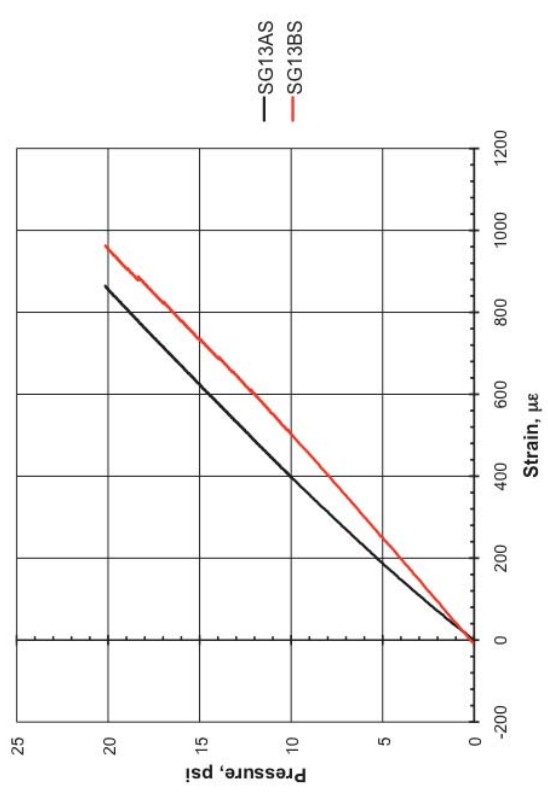


Figure D24. 2.2P test, strain gages SG13AS and SG13BS.

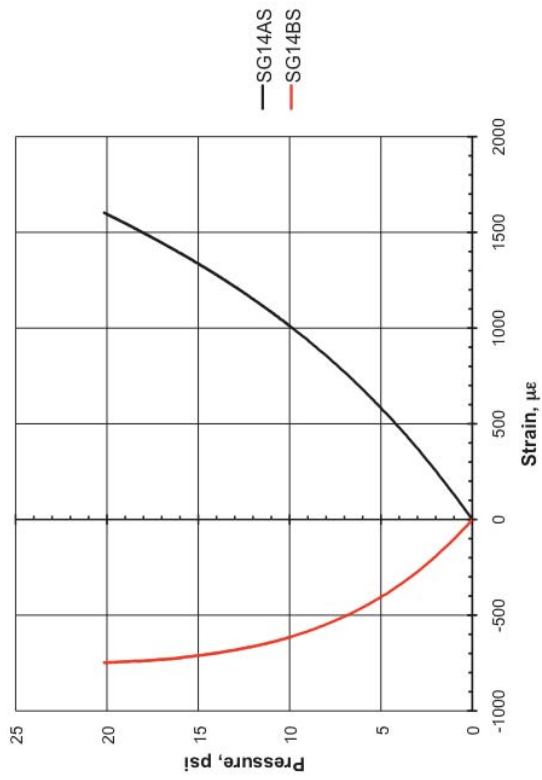


Figure D25. 2.2P test, strain gages SG14AS and SG14BS.

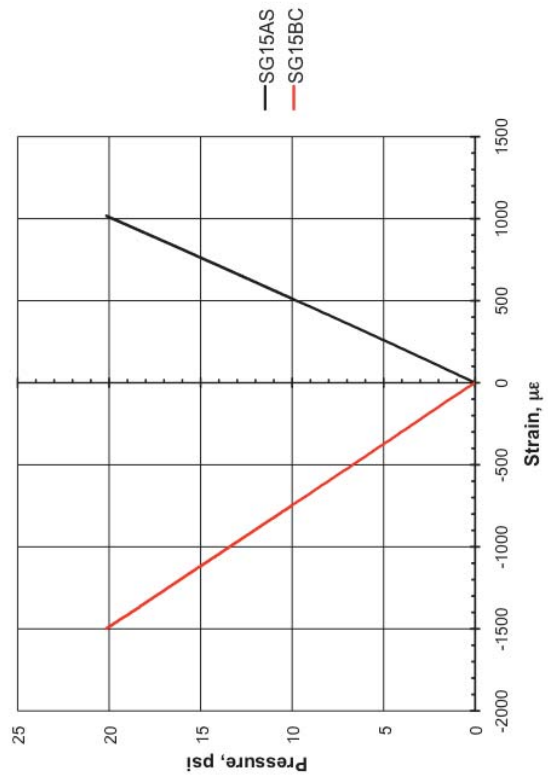


Figure D26. 2.2P test, strain gages SG15AS and SG15BC.

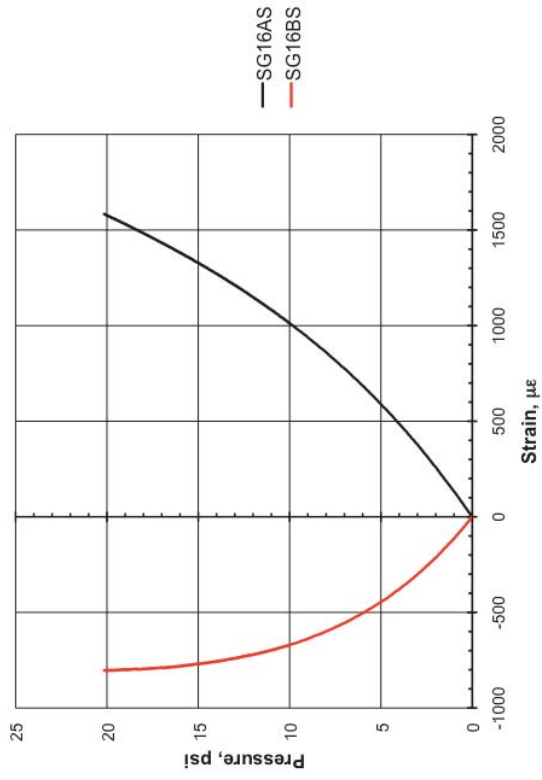


Figure D27. 2.2P test, strain gages SG16AS and SG16BS.

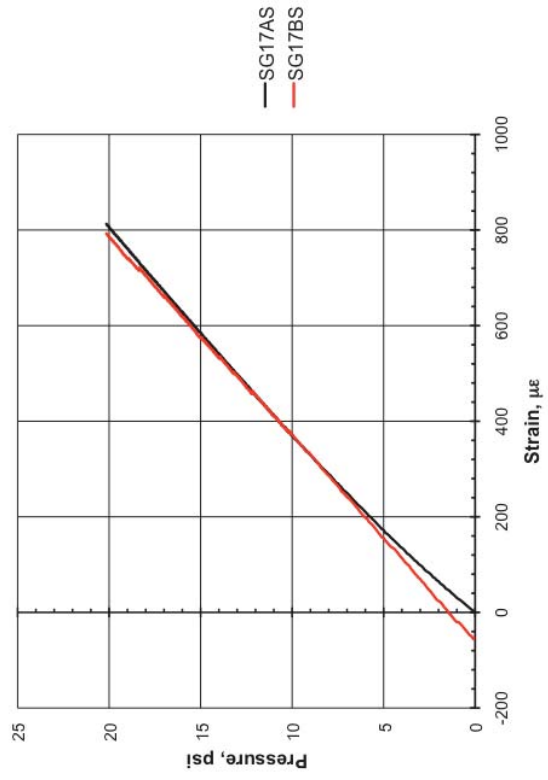


Figure D28. 2.2P test, strain gages SG17AS and SG17BS.

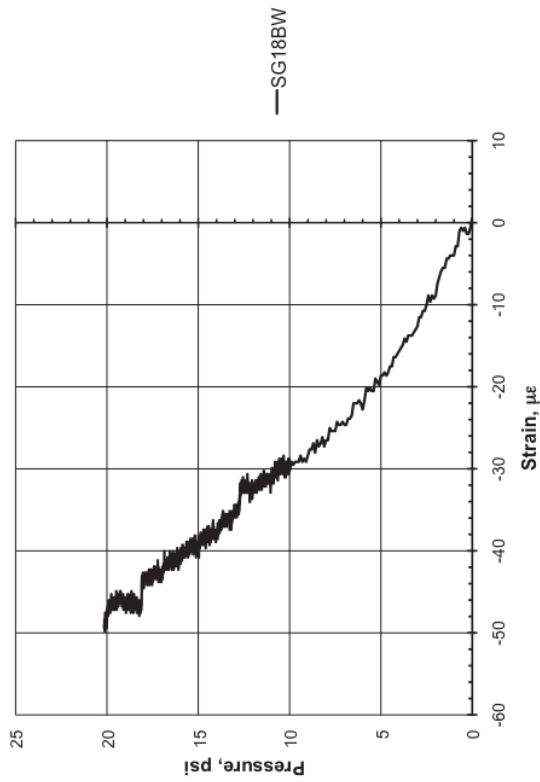


Figure D29. 2.2P test, strain gage SG18BW.

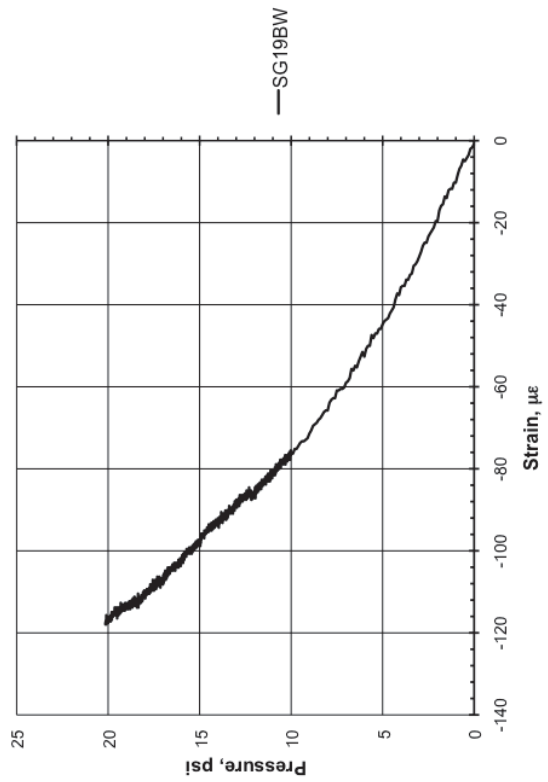


Figure D30. 2.2P test, strain gage SG19BW.

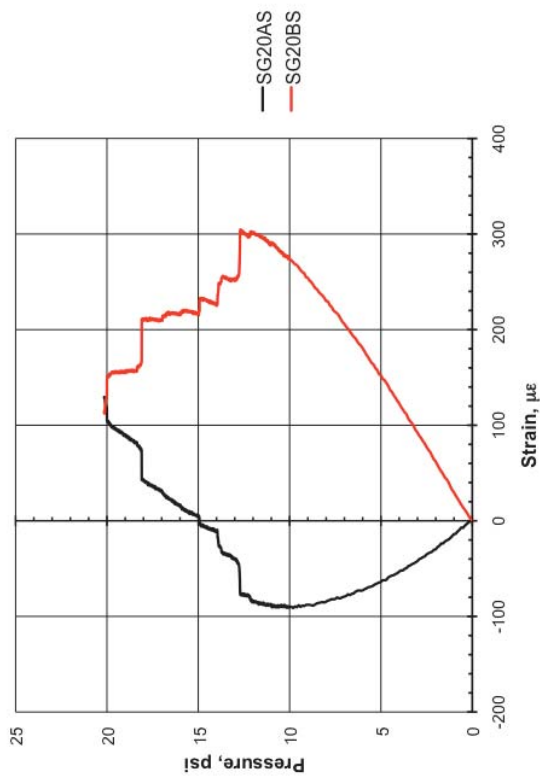


Figure D31. 2.2P test, strain gages SG20AS and SG20BS.

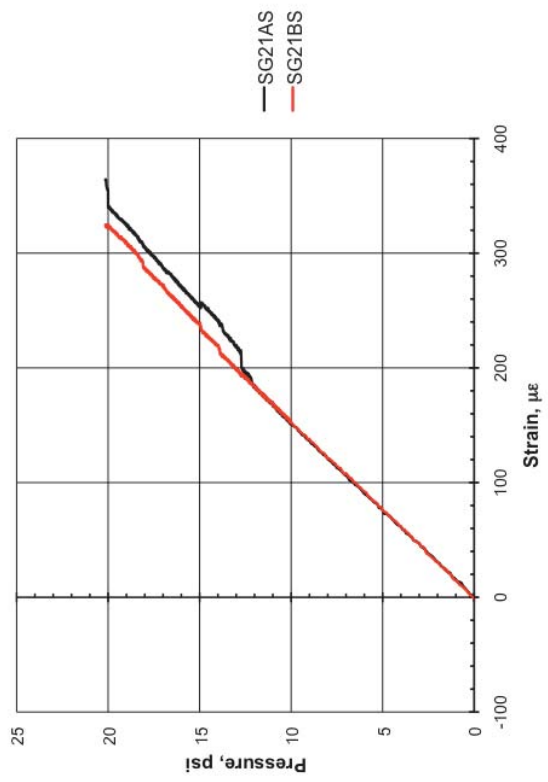


Figure D32. 2.2P test, strain gages SG21AS and SG21BS.

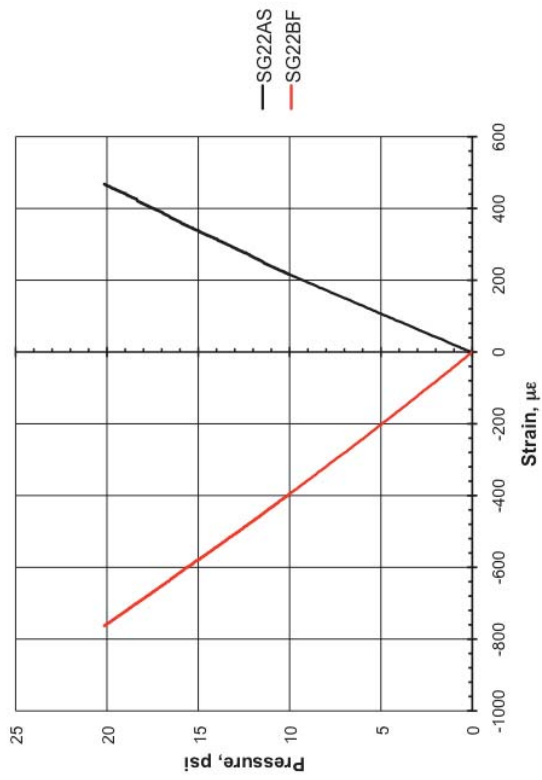


Figure D33. 2.2P test, strain gages SG22AS and SG22BF.

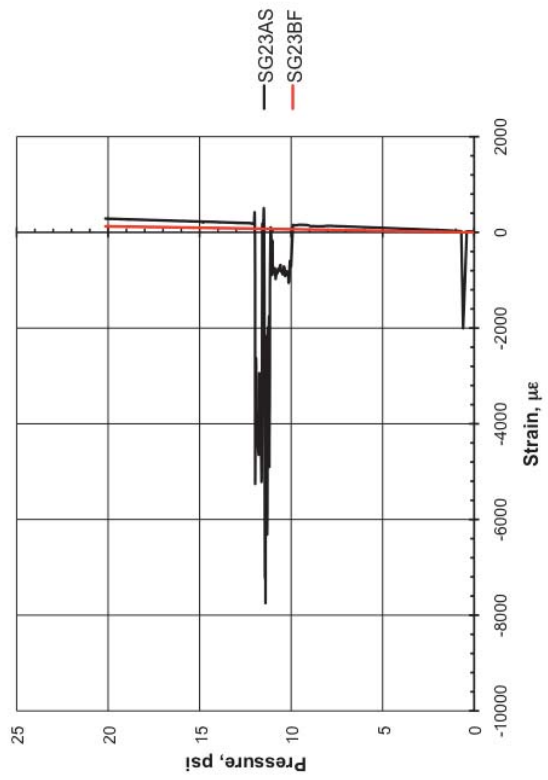


Figure D34. 2.2P test, strain gages SG23AS and SG23BF.

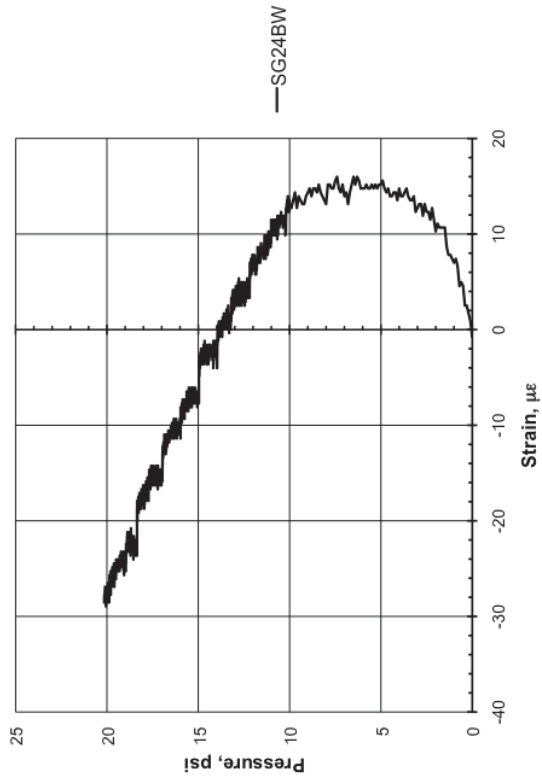


Figure D35. 2.2P test, strain gage SG24BW.

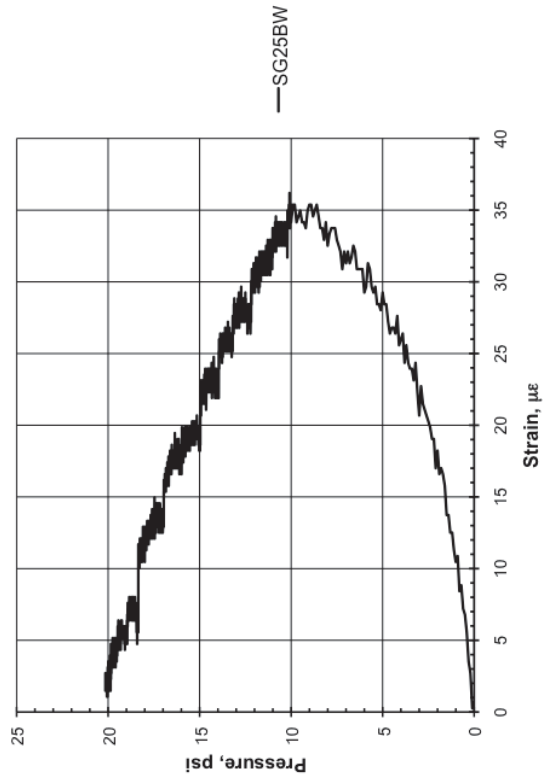


Figure D36. 2.2P test, strain gage SG25BW.

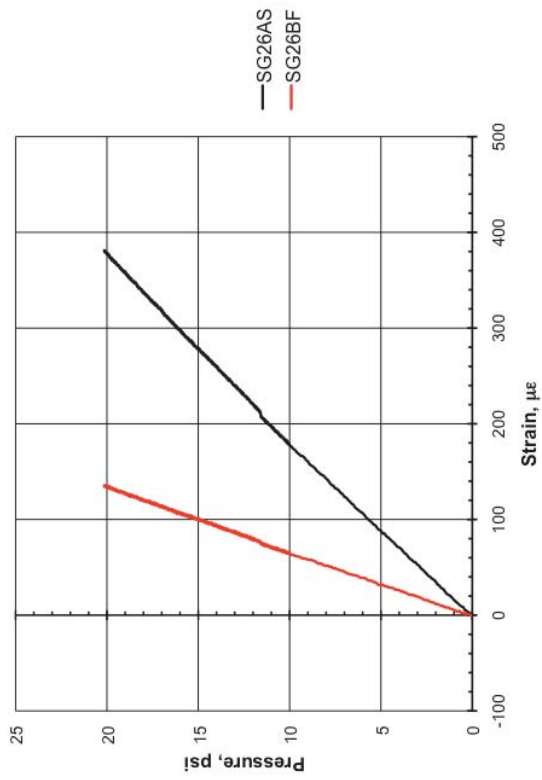


Figure D37. 2.2P test, strain gages SG26AS and SG26BF.

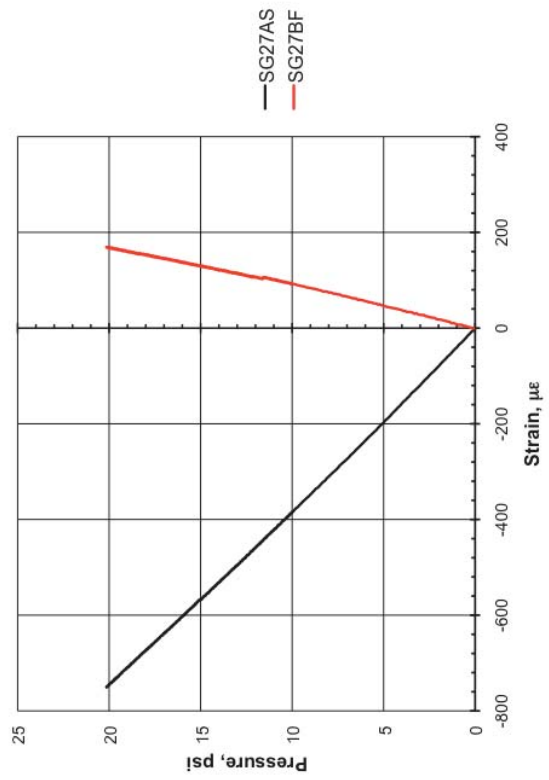


Figure D38. 2.2P test, strain gages SG27AS and SG27BF.

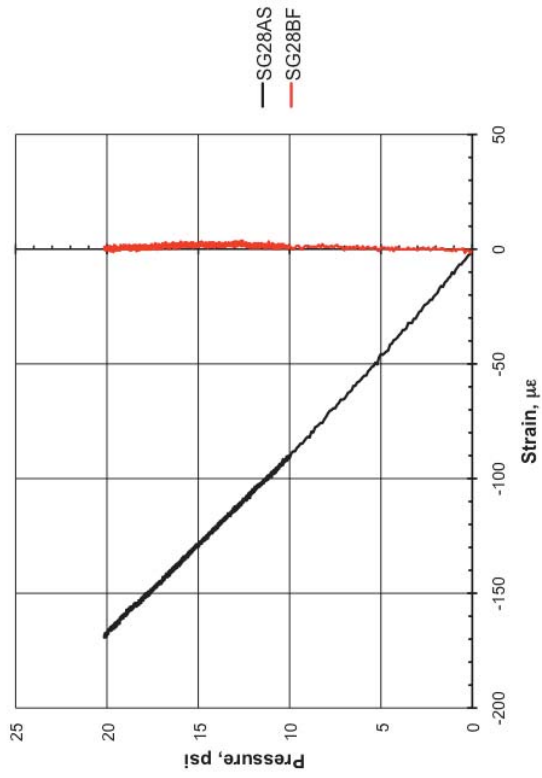


Figure D39. 2.2P test, strain gages SG28AS and SG28BF.

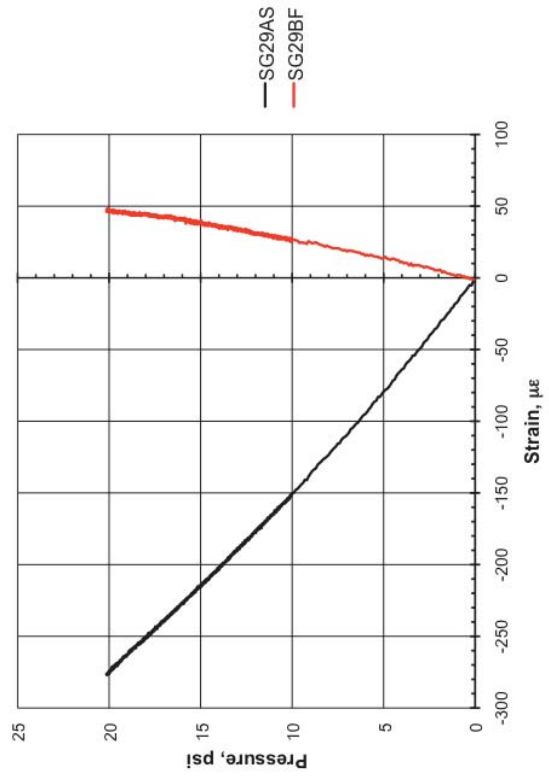
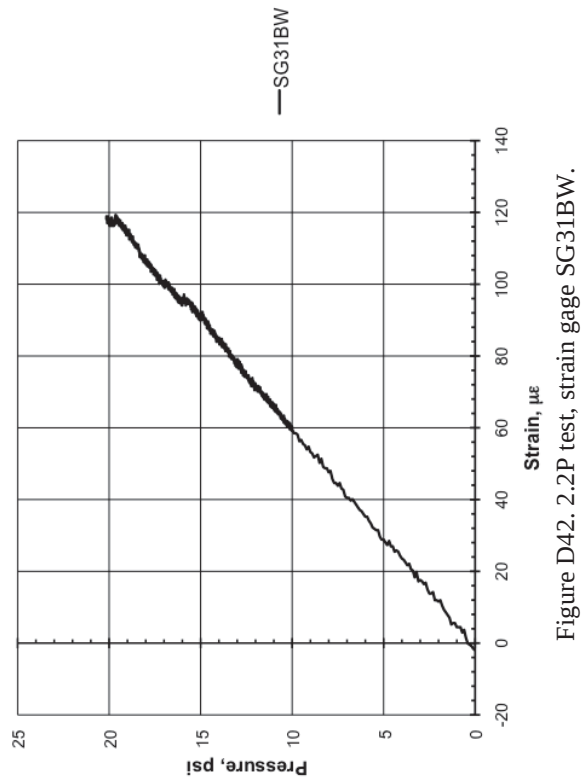
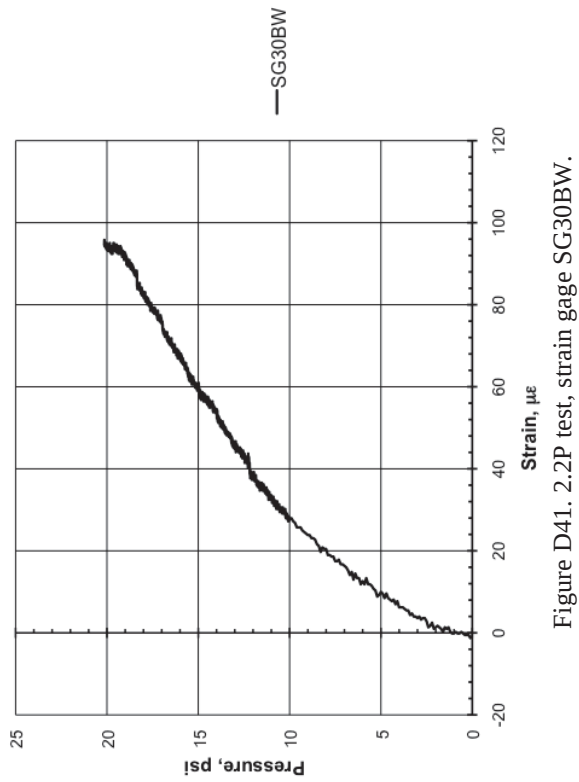
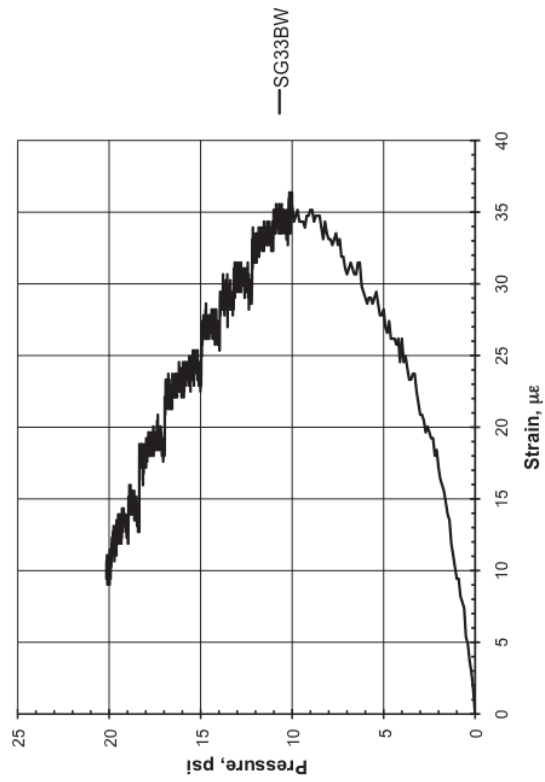
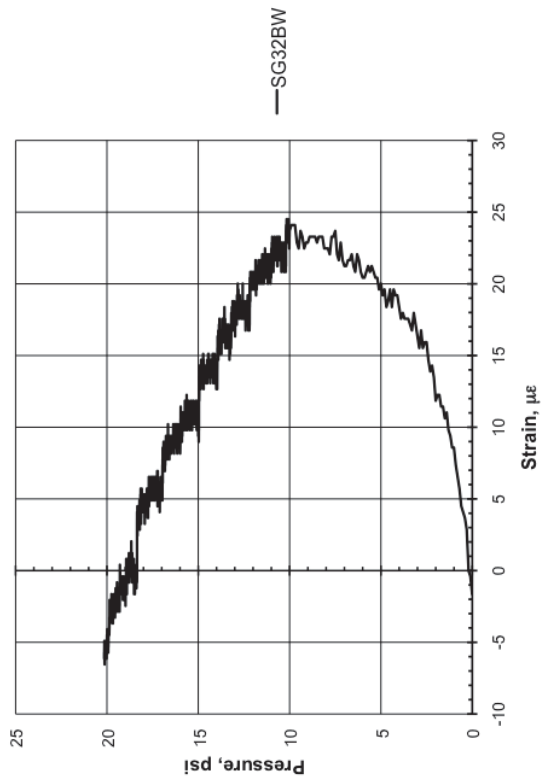


Figure D40. 2.2P test, strain gages SG29AS and SG29BF.





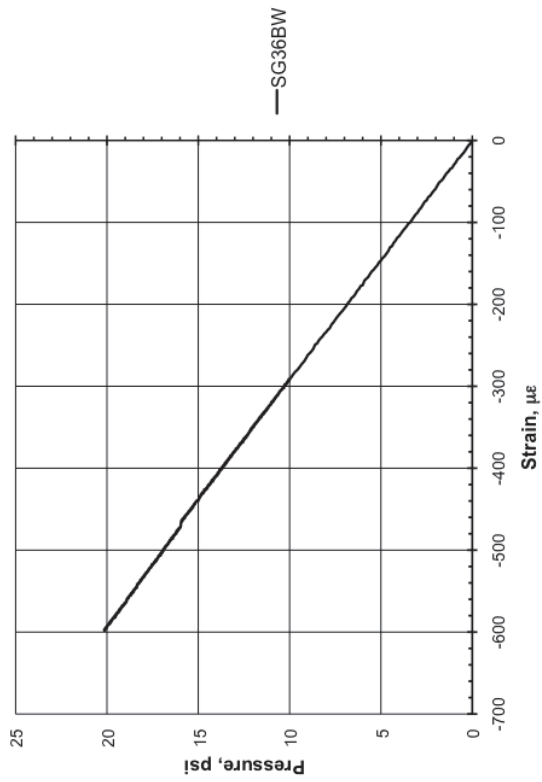


Figure D47. 2.2P test, strain gage SG36BW.

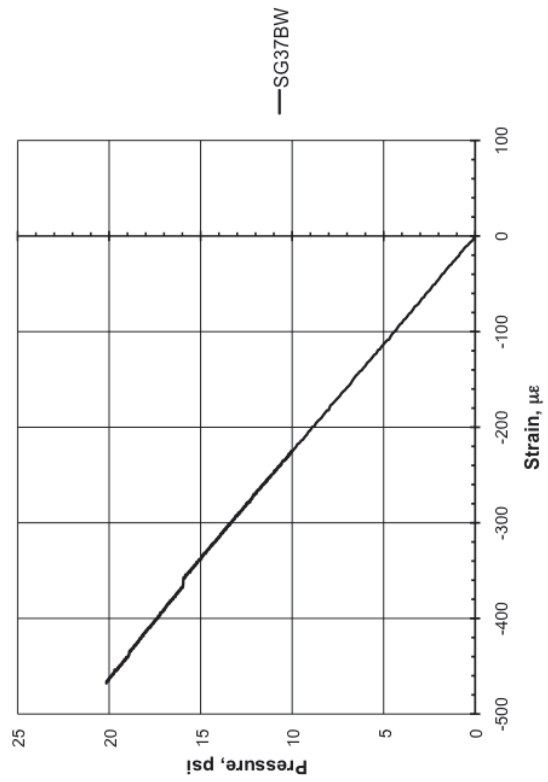


Figure D48. 2.2P test, strain gage SG37BW.

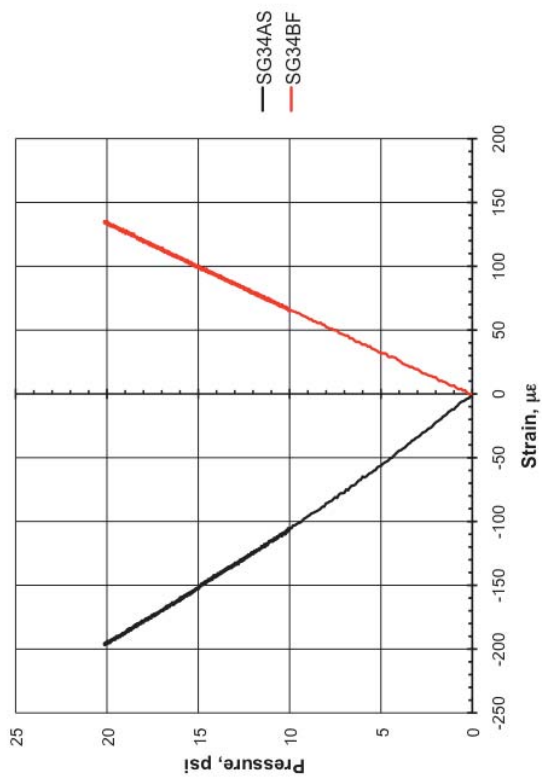


Figure D45. 2.2P test, strain gages SG34AS and SG34BF.

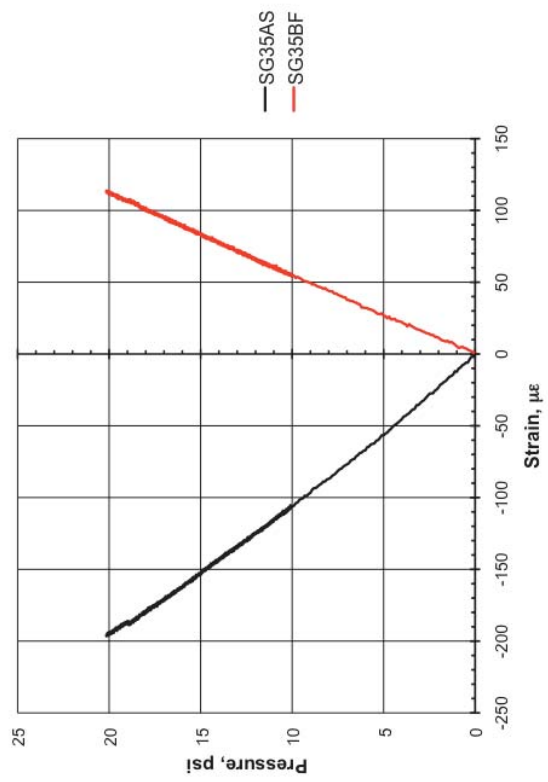


Figure D46. 2.2P test, strain gages SG35AS and SG35BF.

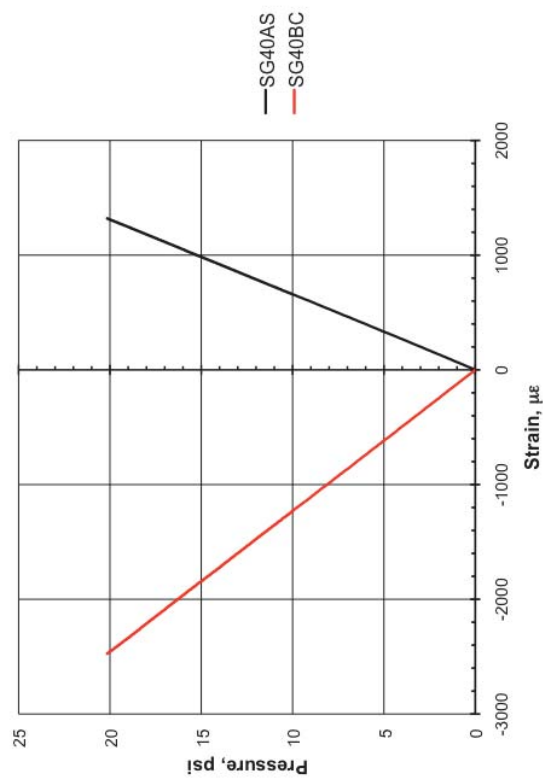


Figure D51. 2.2P test, strain gages SG40AS and SG40BC.

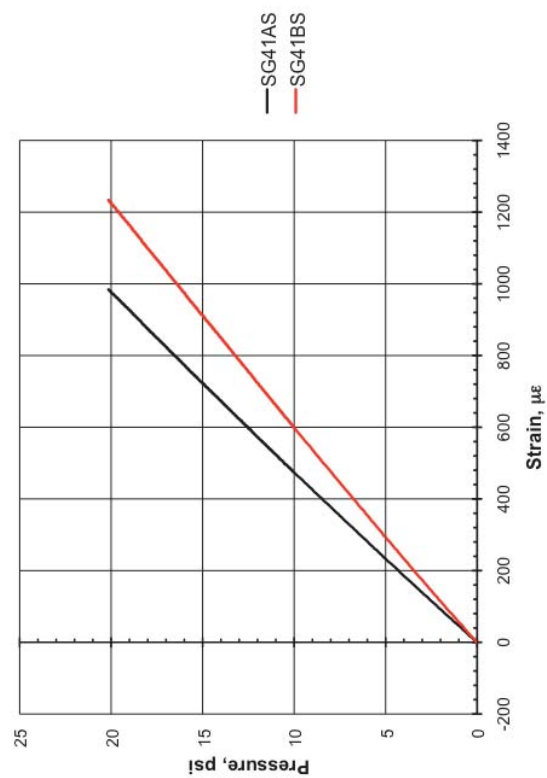


Figure D52. 2.2P test, strain gages SG41AS and SG41BS.

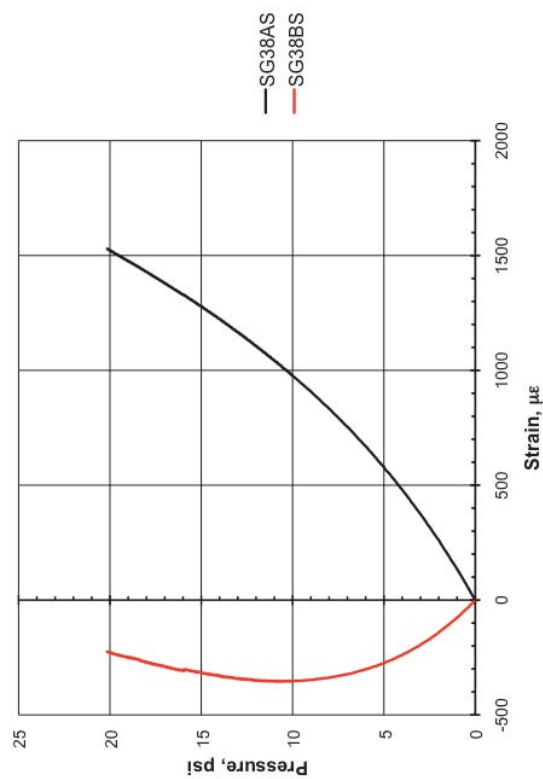


Figure D49. 2.2P test, strain gages SG38AS and SG38BS.

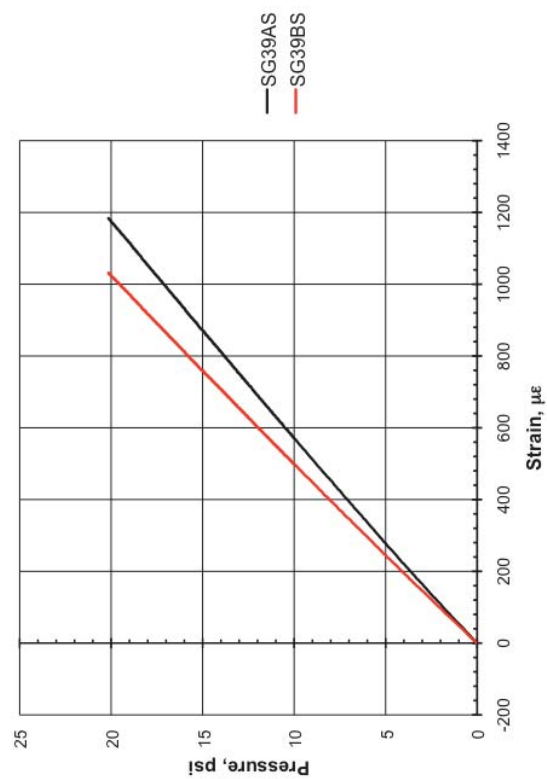


Figure D50. 2.2P test, strain gages SG39AS and SG39BS.

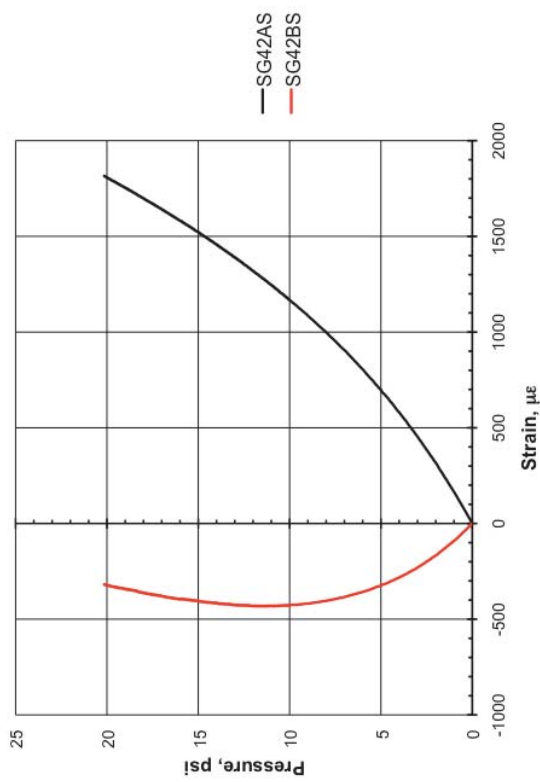


Figure D53. 2.2P test, strain gages SG42AS and SG42BS.

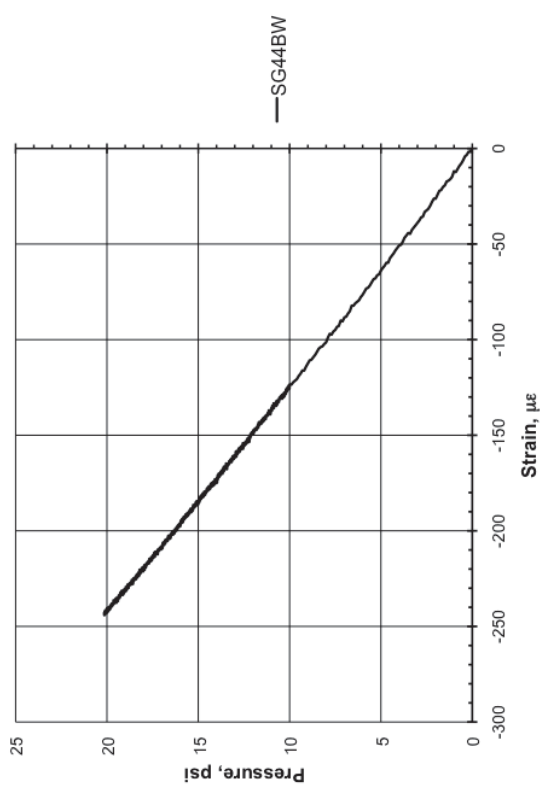


Figure D55. 2.2P test, strain gage SG44BW.

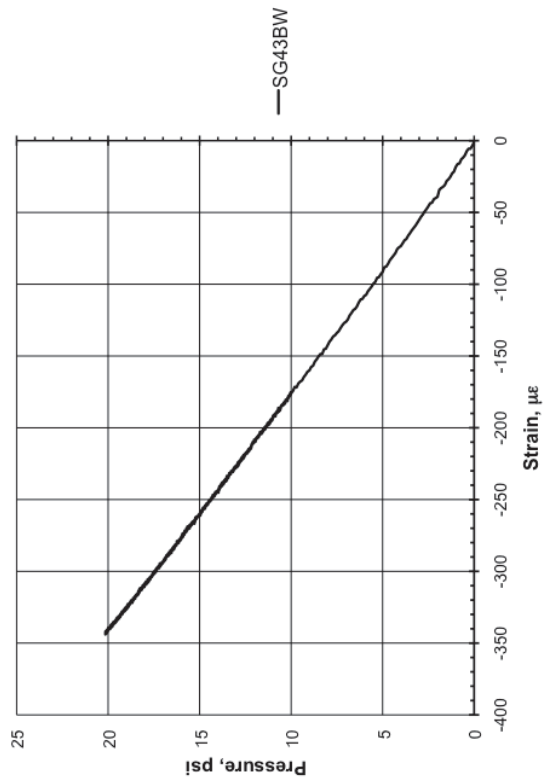


Figure D54. 2.2P test, strain gage SG43BW.

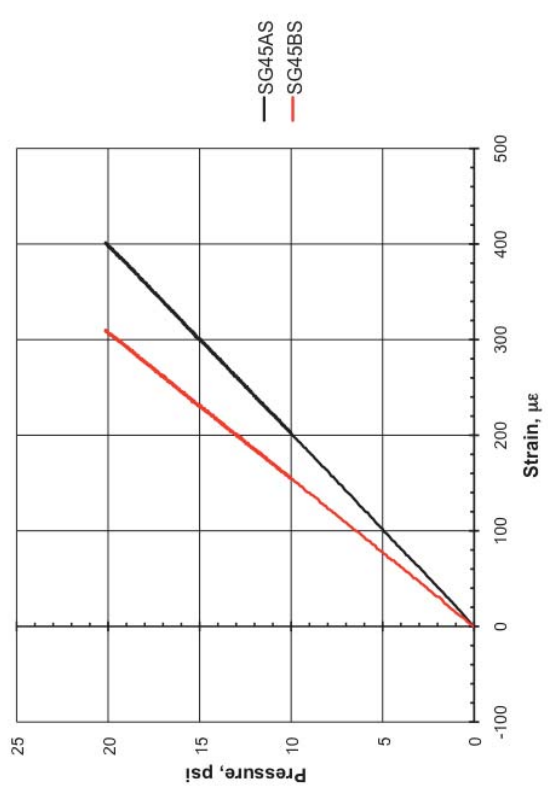


Figure D56. 2.2P test, strain gages SG45AS and SG45BS.

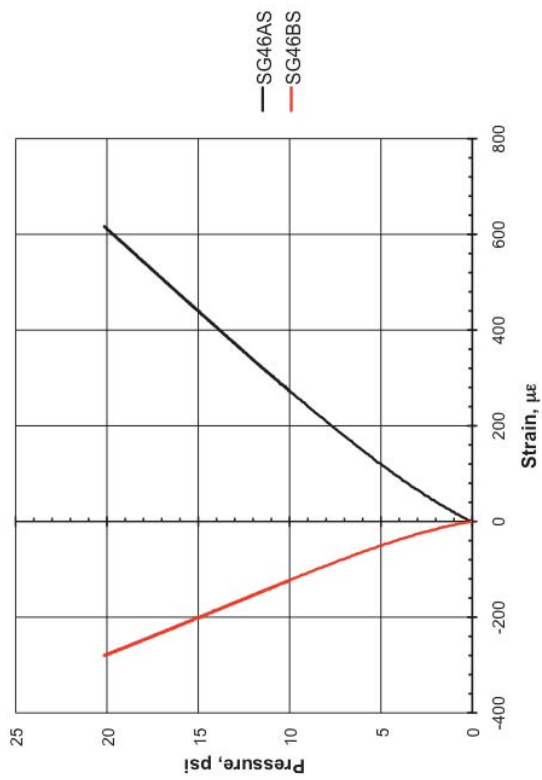


Figure D57. 2.2P test, strain gages SG46AS and SG46BS.

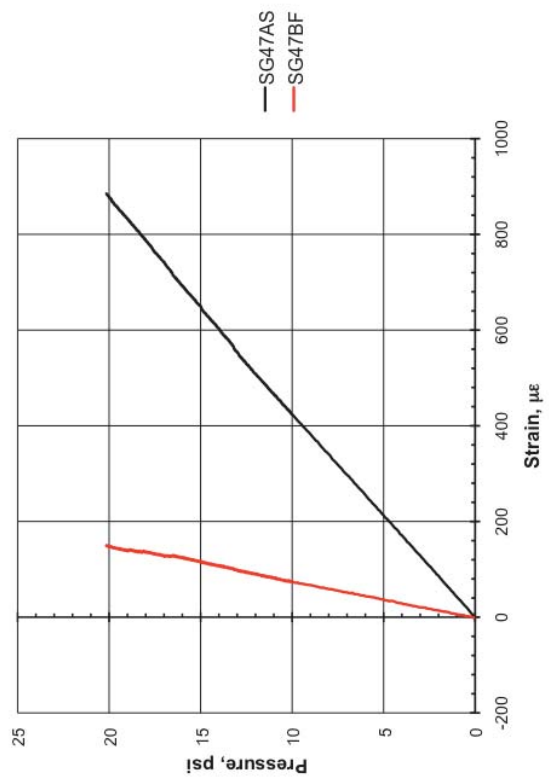


Figure D58. 2.2P test, strain gages SG47AS and SG47BF.

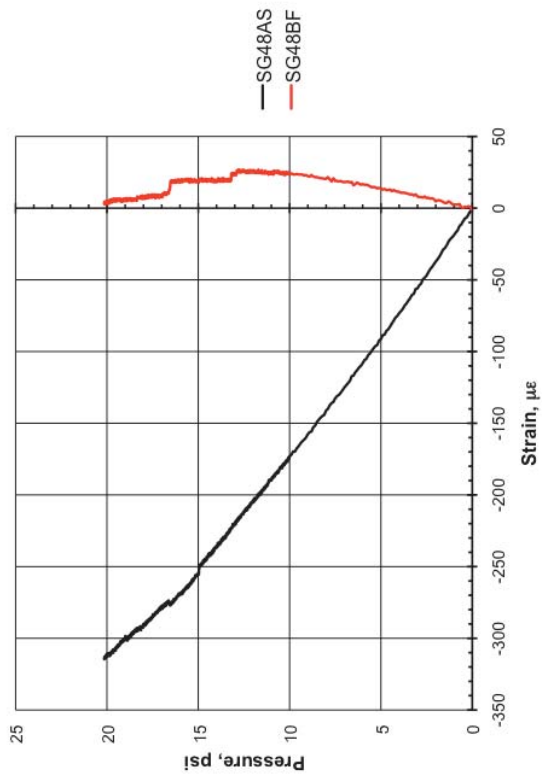


Figure D59. 2.2P test, strain gages SG48AS and SG48BF.

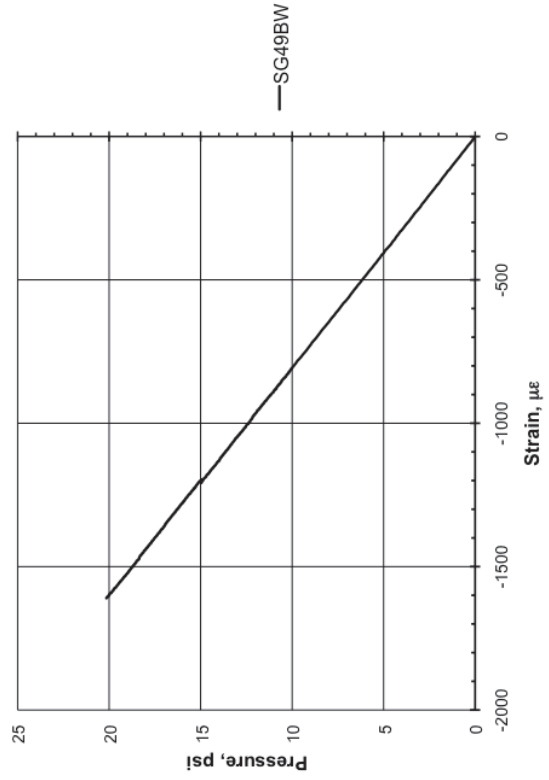


Figure D60. 2.2P test, strain gage SG49BW.

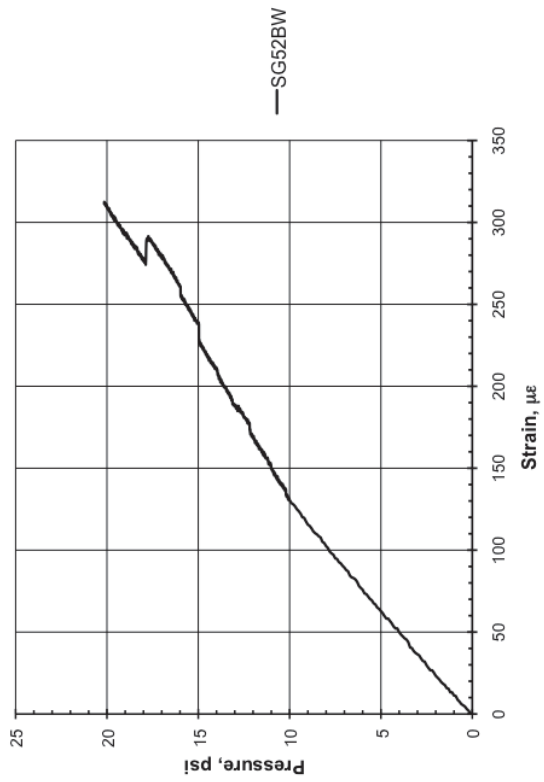


Figure D63. 2.2P test, strain gage SG52BW.

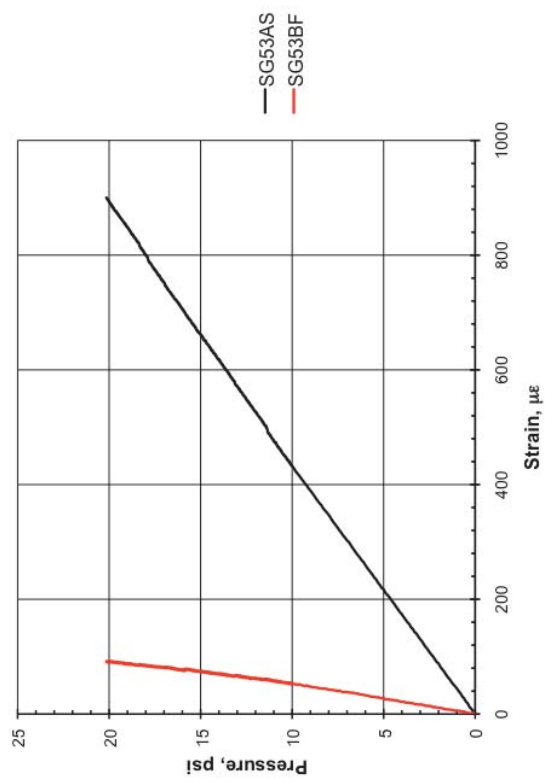


Figure D64. 2.2P test, strain gages SG53AS and SG53BF.

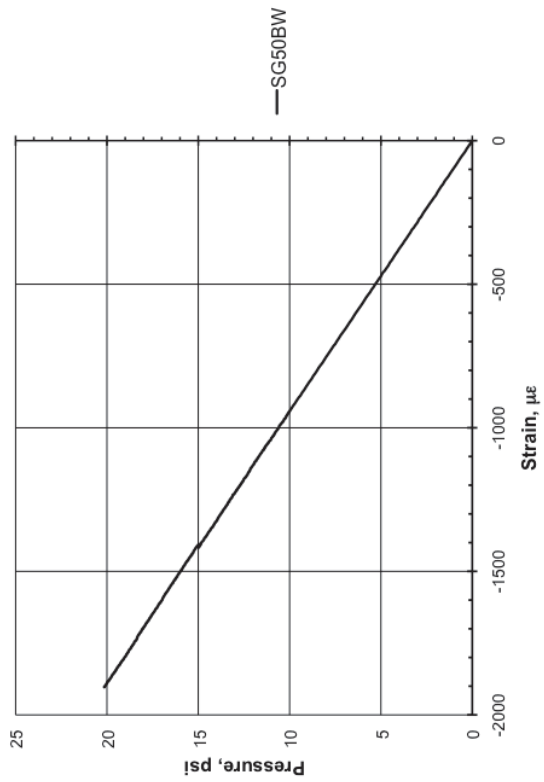


Figure D61. 2.2P test, strain gage SG50BW.

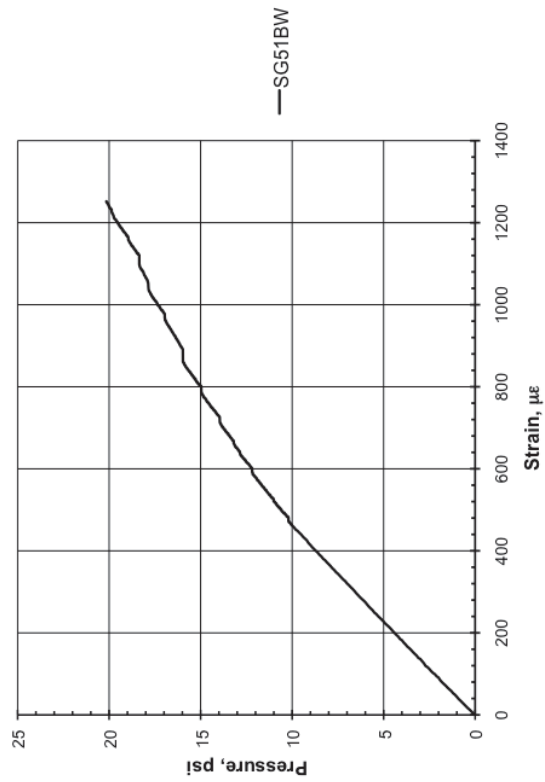


Figure D62. 2.2P test, strain gage SG51BW.

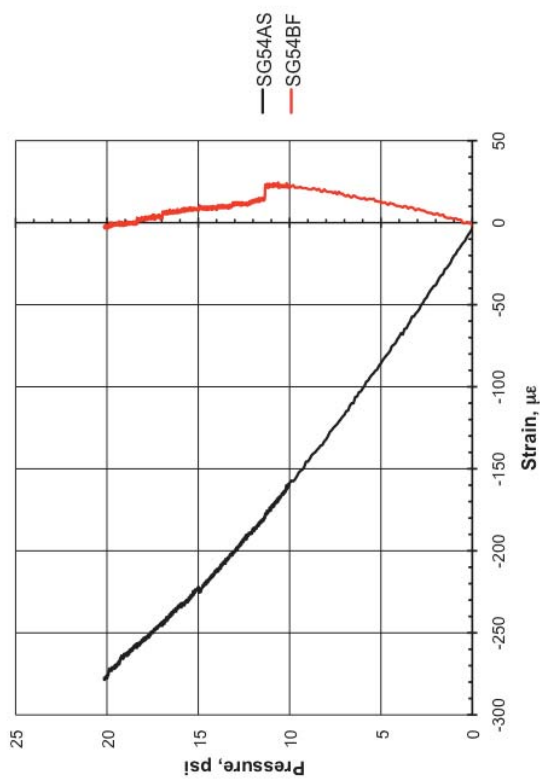


Figure D65. 2.2P test, strain gages SG54AS and SG54BF.

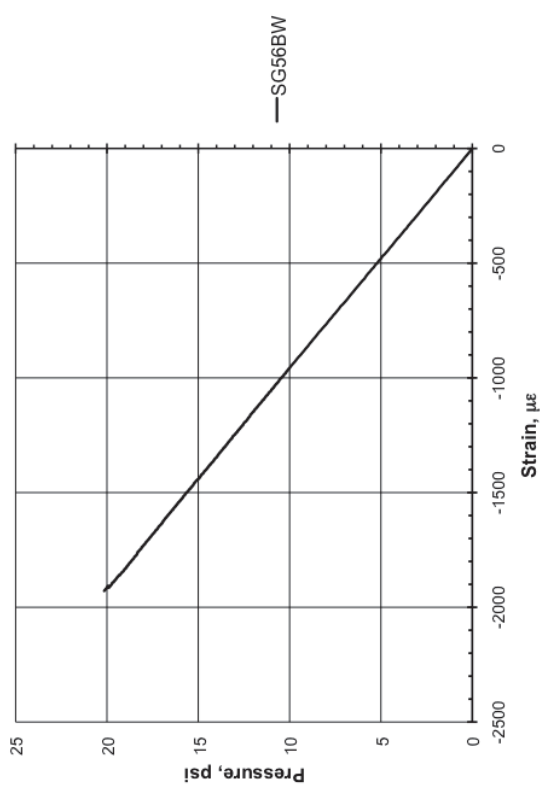


Figure D67. 2.2P test, strain gage SG56BW.

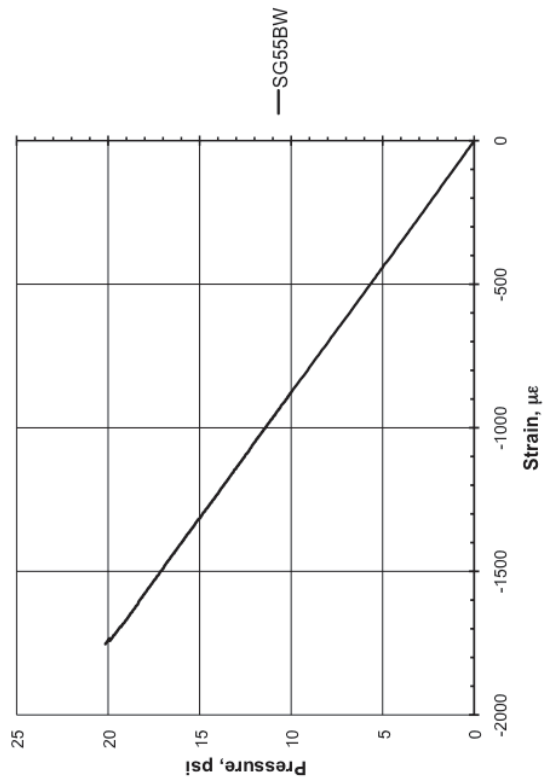


Figure D66. 2.2P test, strain gage SG55BW.

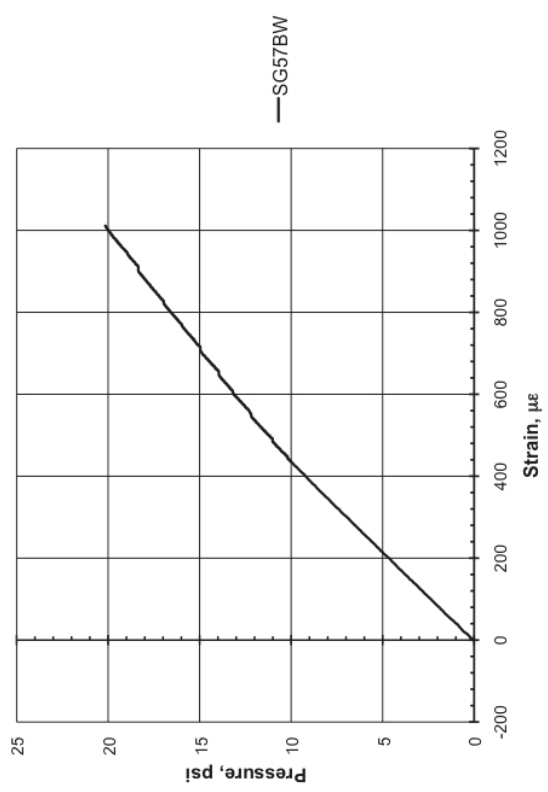


Figure D68. 2.2P test, strain gage SG57BW.

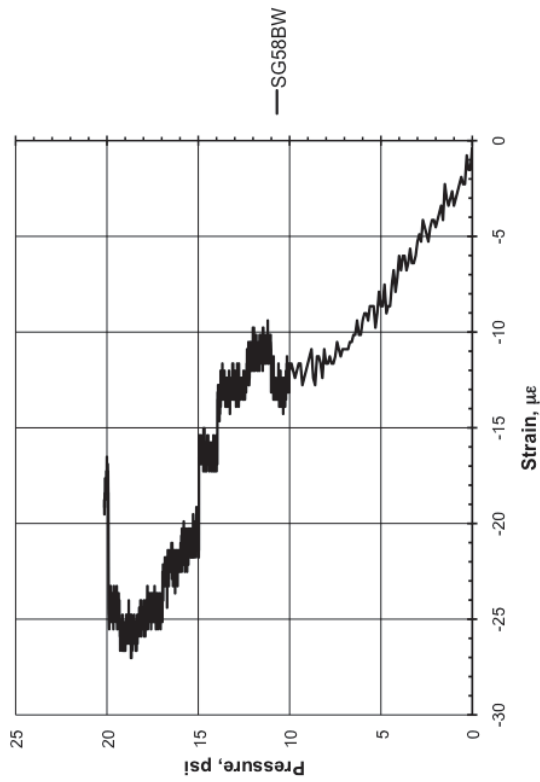


Figure D69. 2.2P test, strain gage SG58BW.

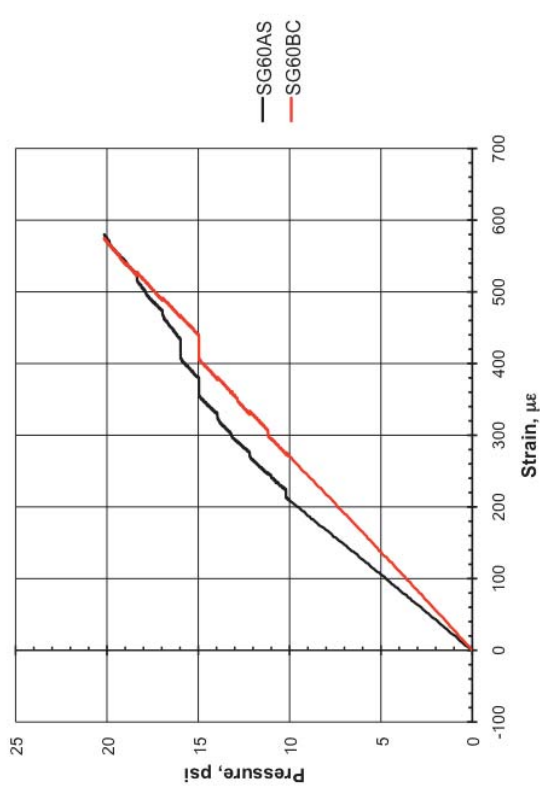


Figure D71. 2.2P test, strain gages SG60AS and SG60BC.

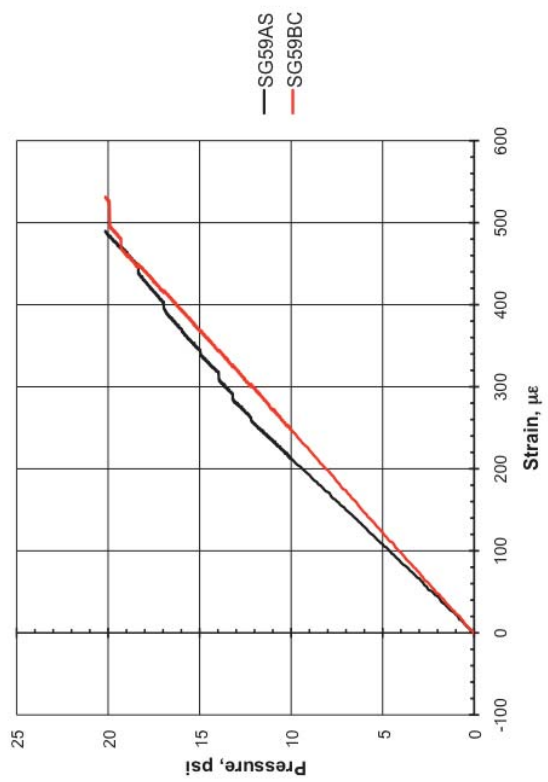


Figure D70. 2.2P test, strain gages SG59AS and SG59BC.

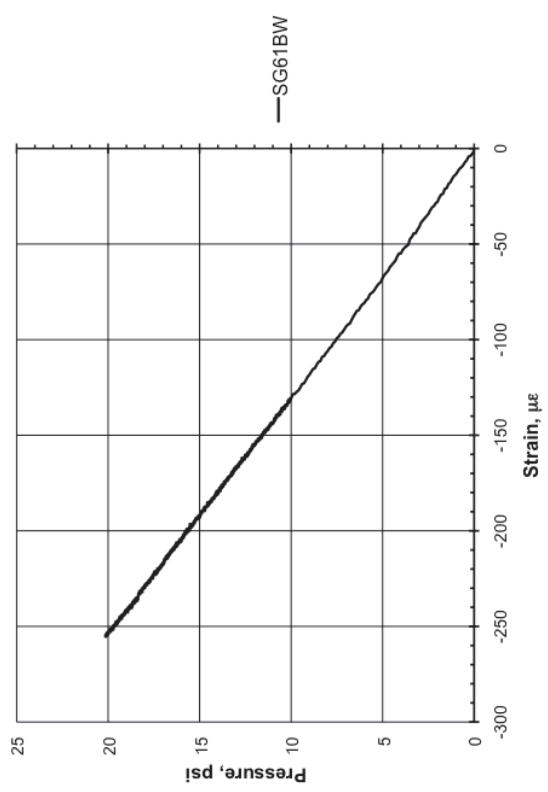


Figure D72. 2.2P test, strain gage SG61BW.



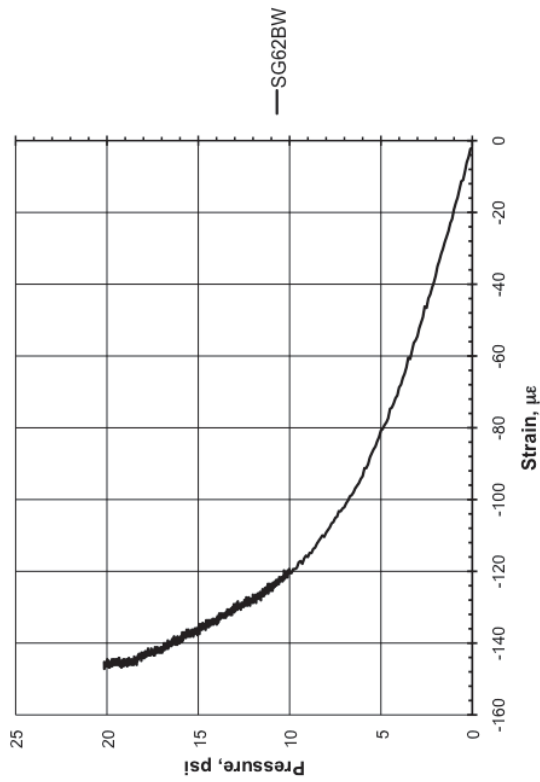


Figure D73. 2.2P test, strain gage SG62BW.

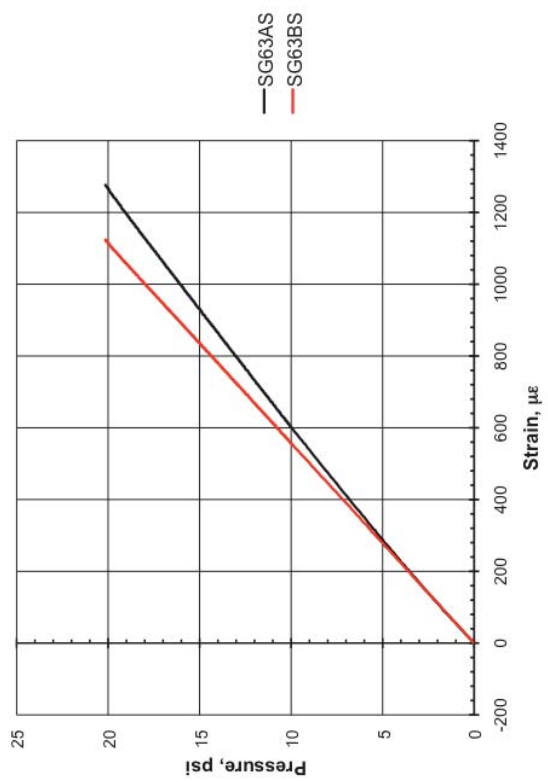


Figure D74. 2.2P test, strain gages SG63AS and SG63BS.

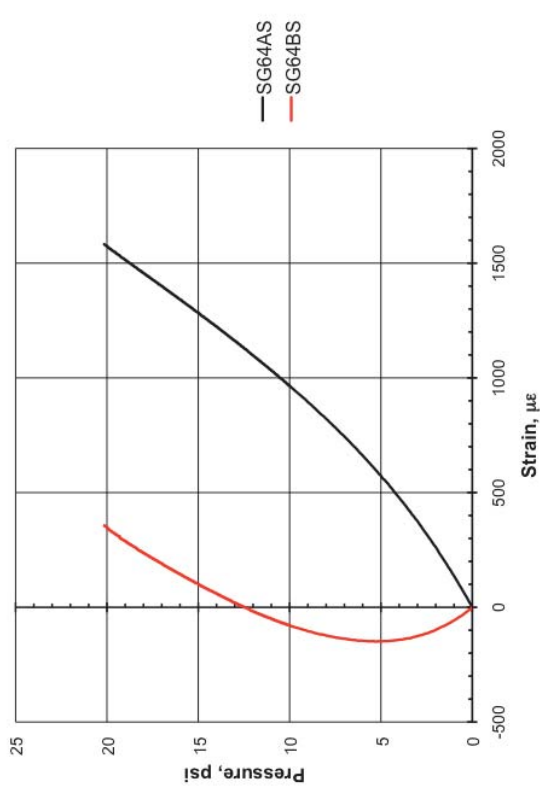


Figure D75. 2.2P test, strain gages SG64AS and SG64BS.

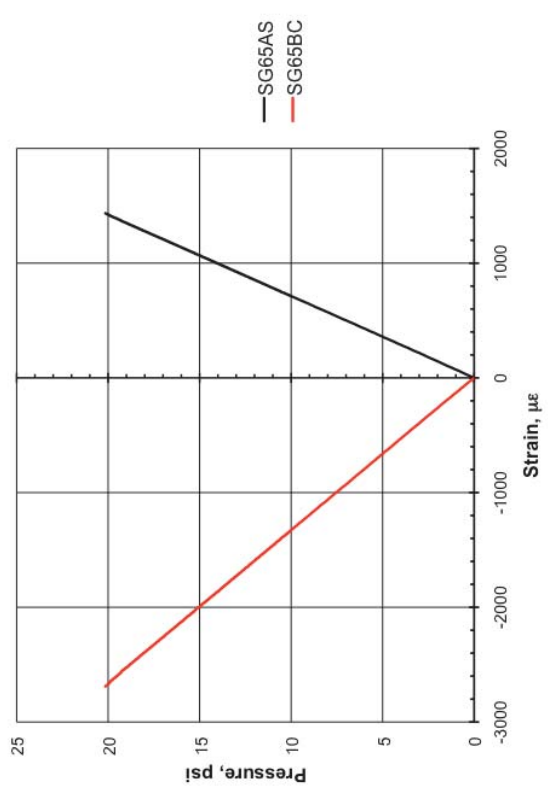


Figure D76. 2.2P test, strain gages SG65AS and SG65BC.

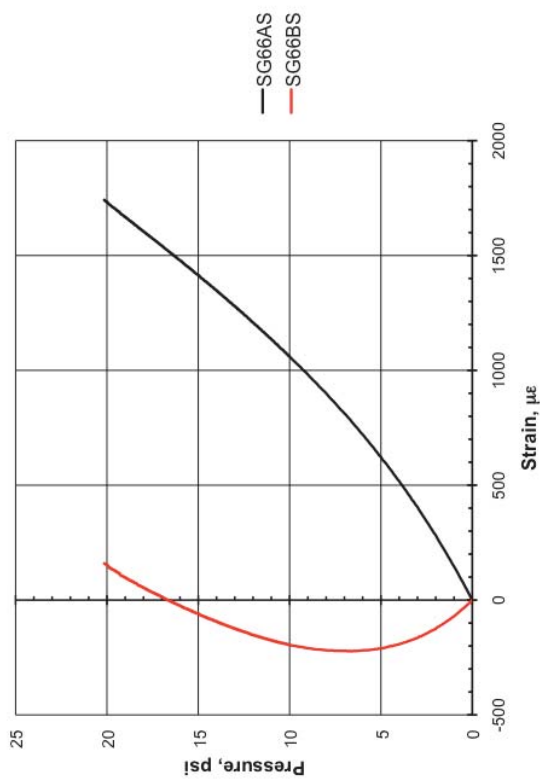


Figure D77. 2.2P test, strain gages SG66AS and SG66BS.

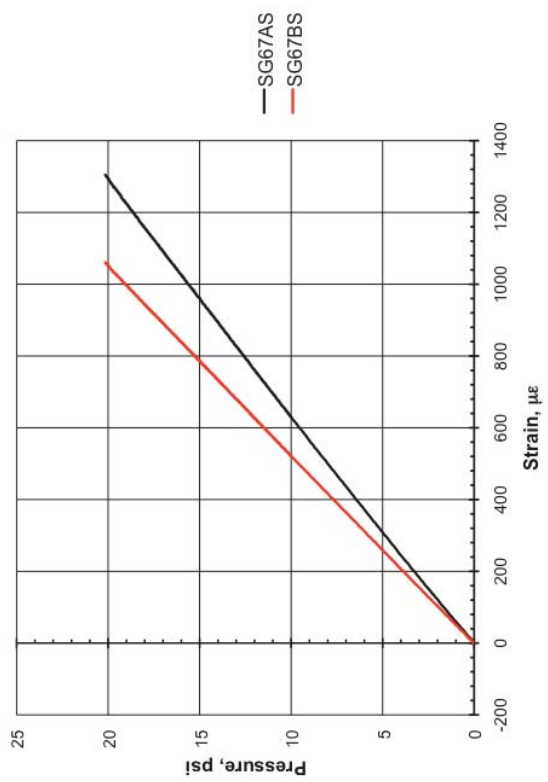


Figure D78. 2.2P test, strain gages SG67AS and SG67BS.

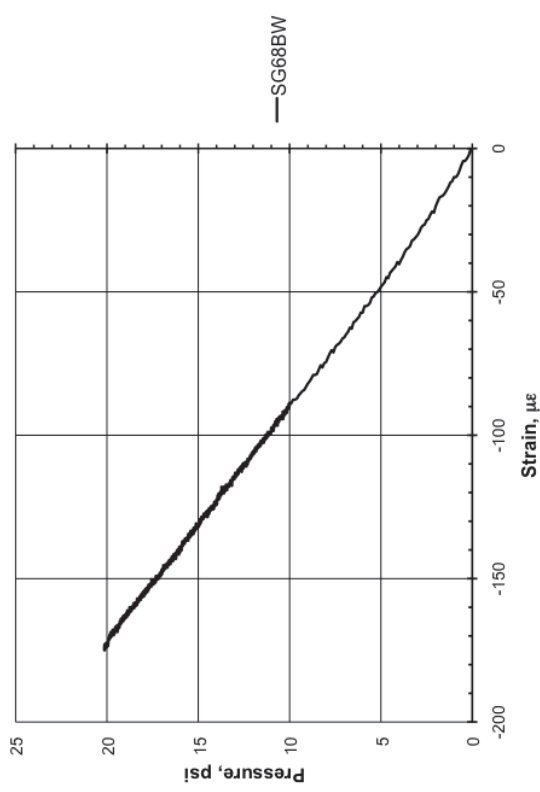


Figure D79. 2.2P test, strain gage SG68BW.

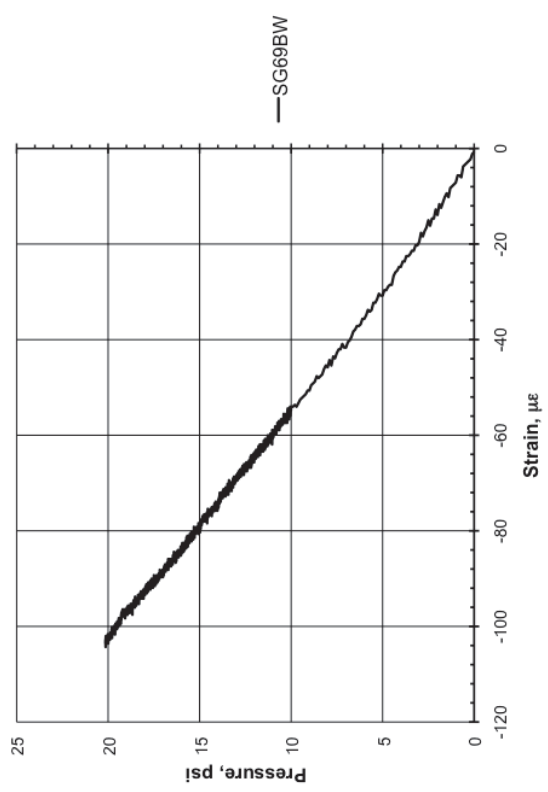


Figure D80. 2.2P test, strain gage SG69BW.

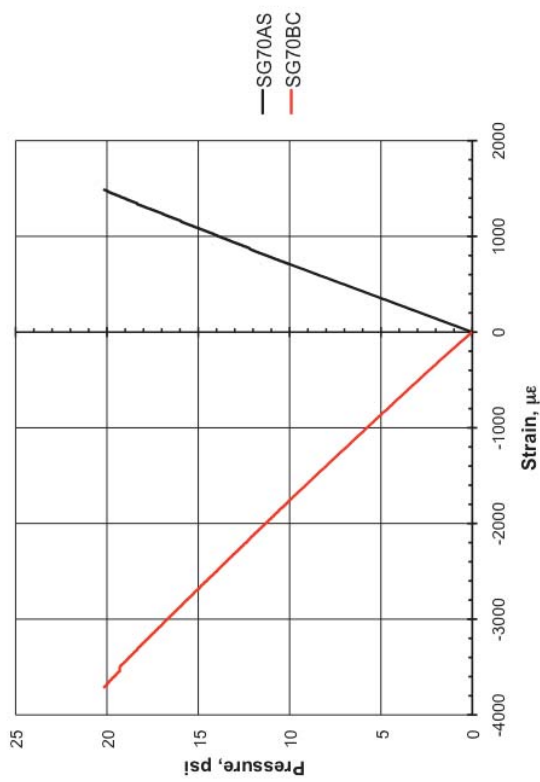


Figure D81. 2.2P test, strain gages SG70AS and SG70BC.

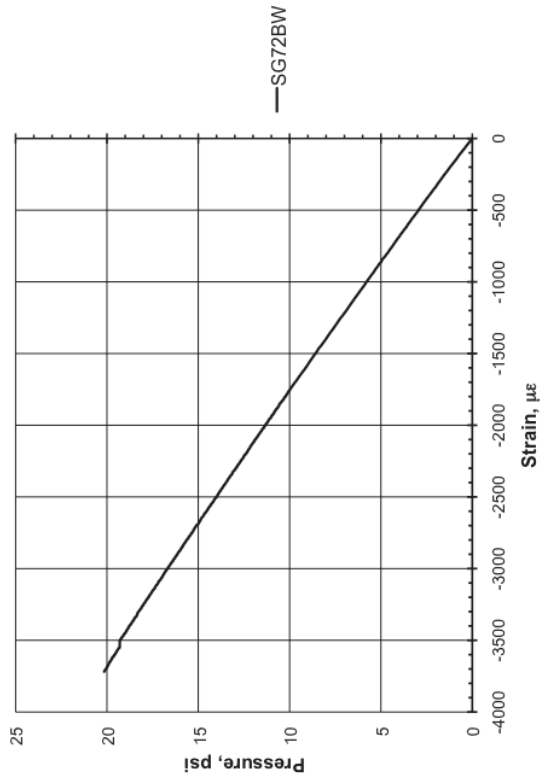


Figure D83. 2.2P test, strain gage SG72BW.

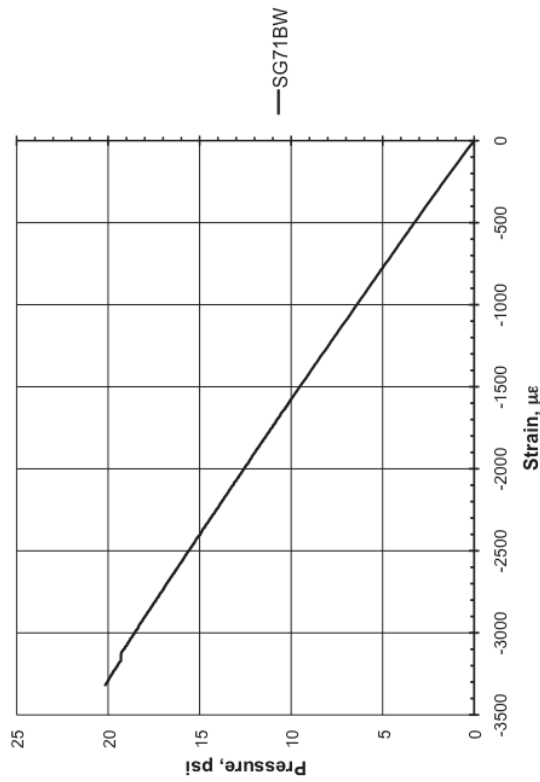


Figure D82. 2.2P test, strain gage SG71BW.

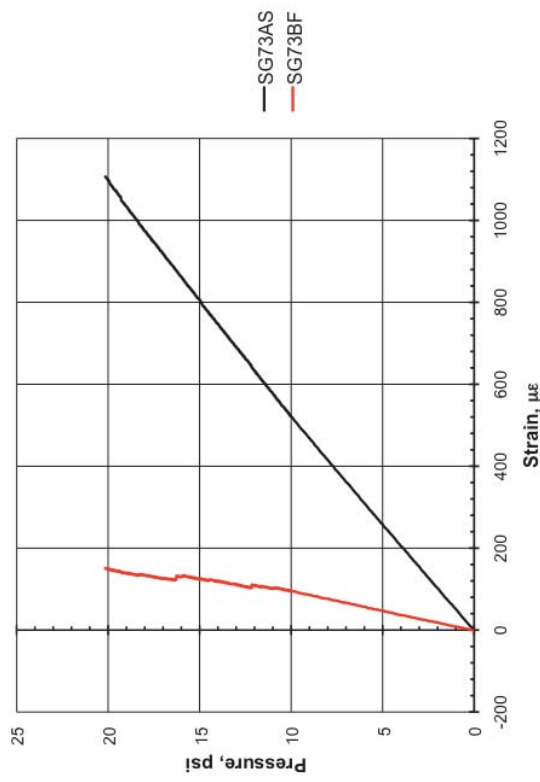


Figure D84. 2.2P test, strain gages SG73AS and SG73BF.

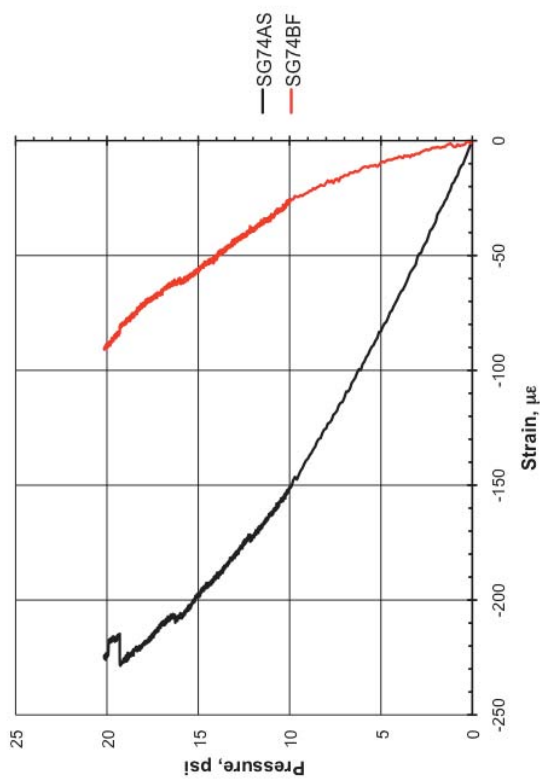


Figure D85. 2.2P test, strain gages SG74AS and SG74BF.

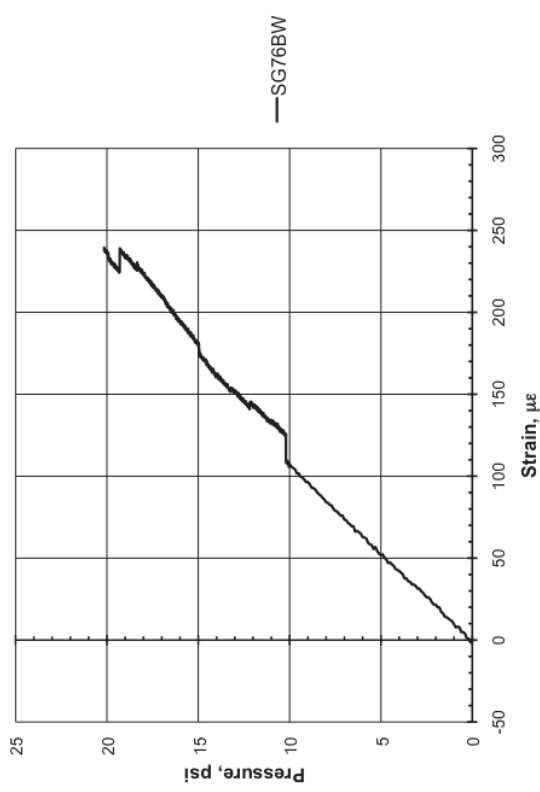


Figure D87. 2.2P test, strain gage SG76BW.

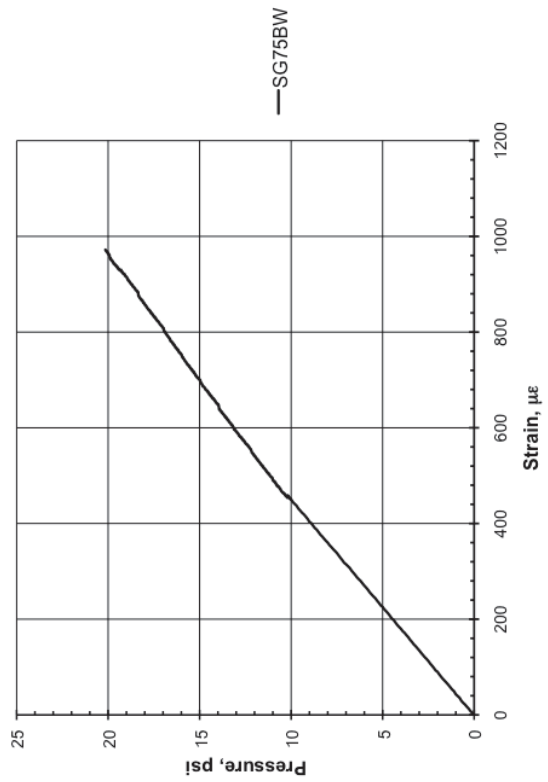


Figure D86. 2.2P test, strain gage SG75BW.

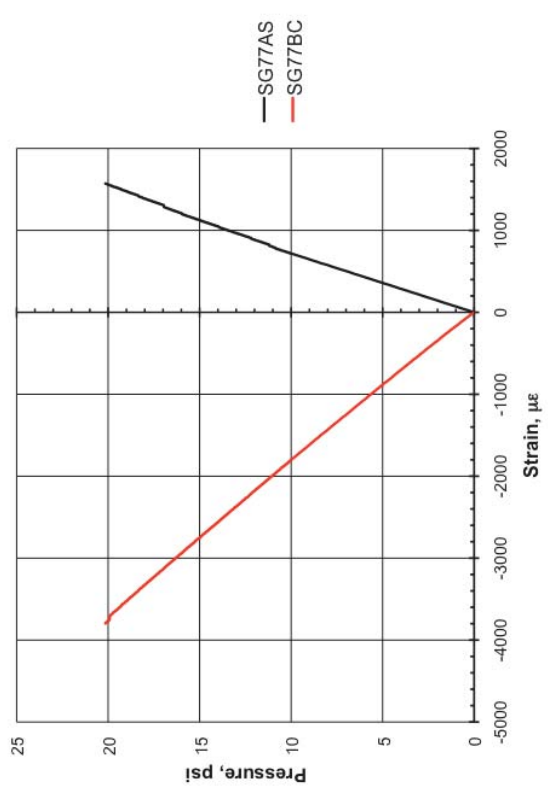


Figure D88. 2.2P test, strain gages SG77AS and SG77BC.

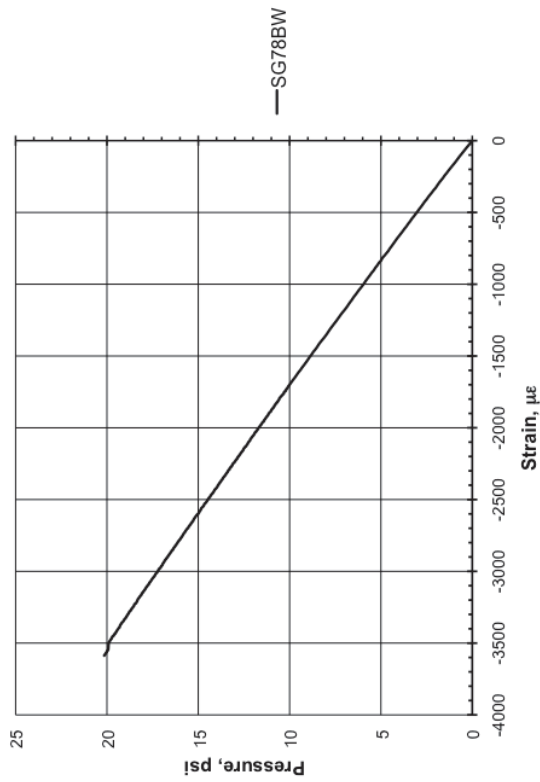


Figure D89. 2.2P test, strain gage SG78BW.

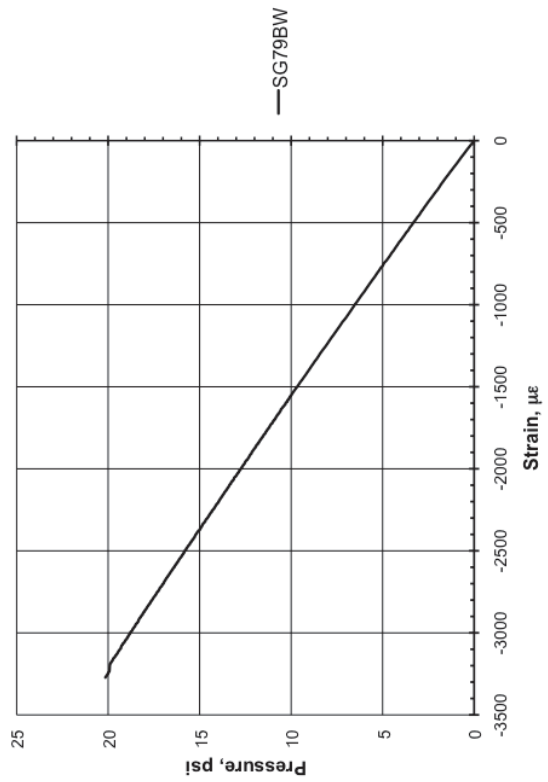


Figure D90. 2.2P test, strain gage SG70BW.

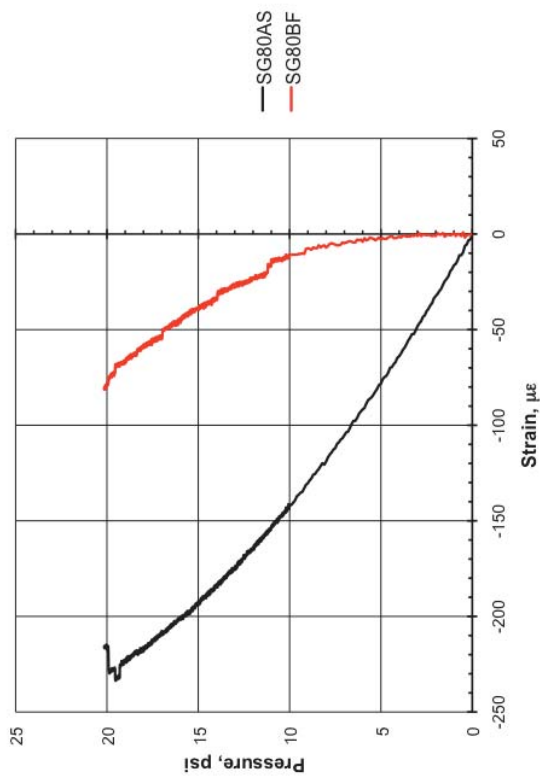


Figure D91. 2.2P test, strain gages SG80AS and SG80BF.

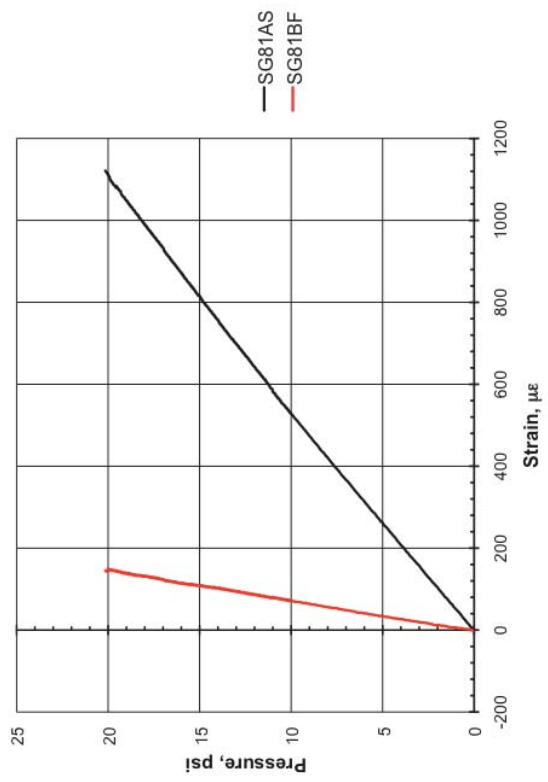


Figure D92. 2.2P test, strain gages SG81AS and SG81BF.

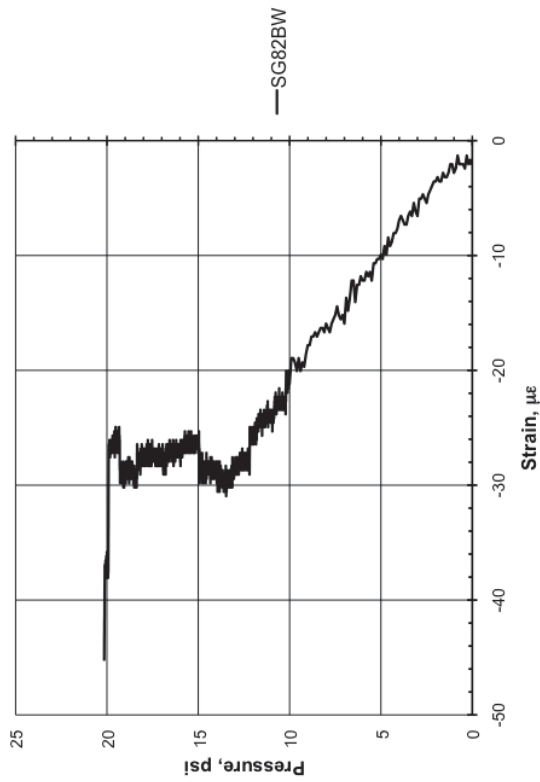


Figure D93. 2.2P test, strain gage SG82BW.

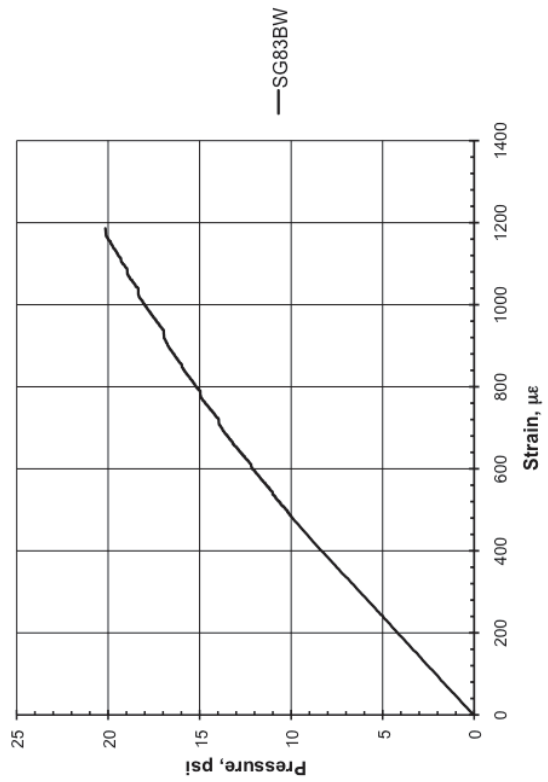


Figure D94. 2.2P test, strain gage SG83BW.

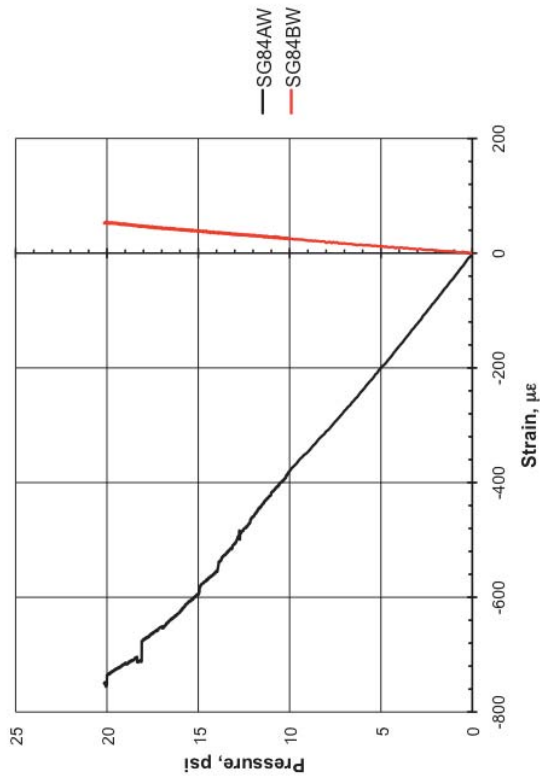


Figure D95. 2.2P test, strain gages SG84AW and SG84BW.

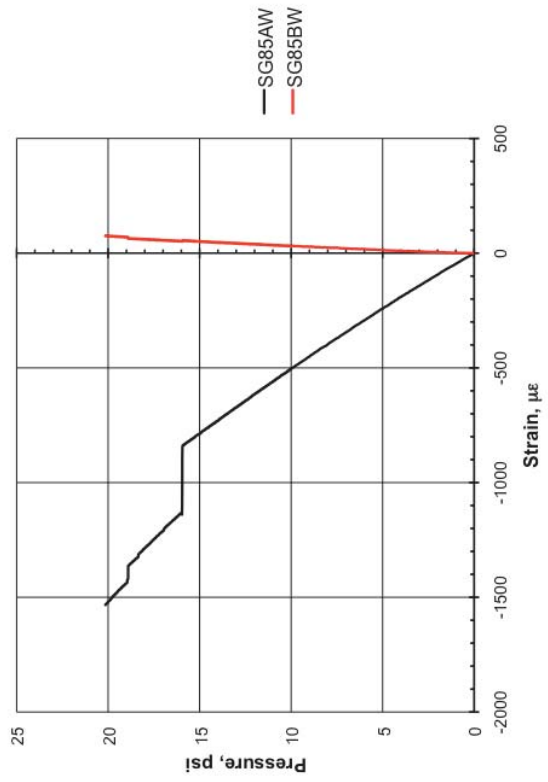


Figure D96. 2.2P test, strain gages SG85AW and SG85BW.

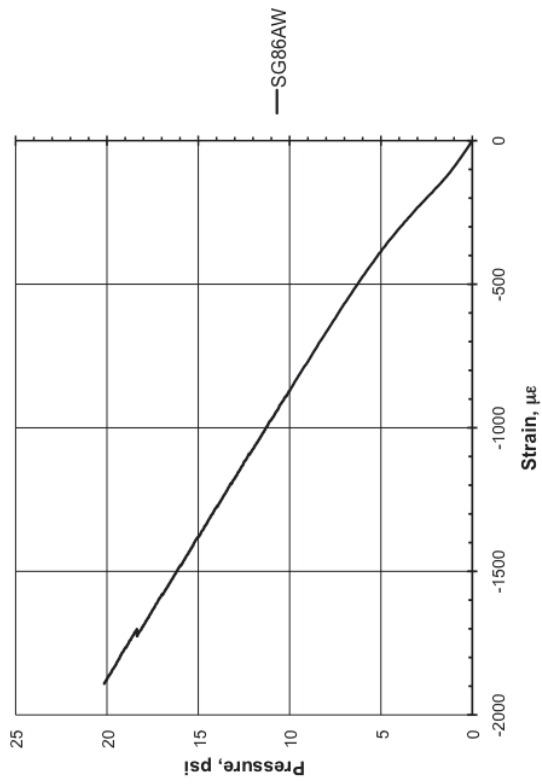


Figure D97. 2.2P test, strain gage SG86AW.

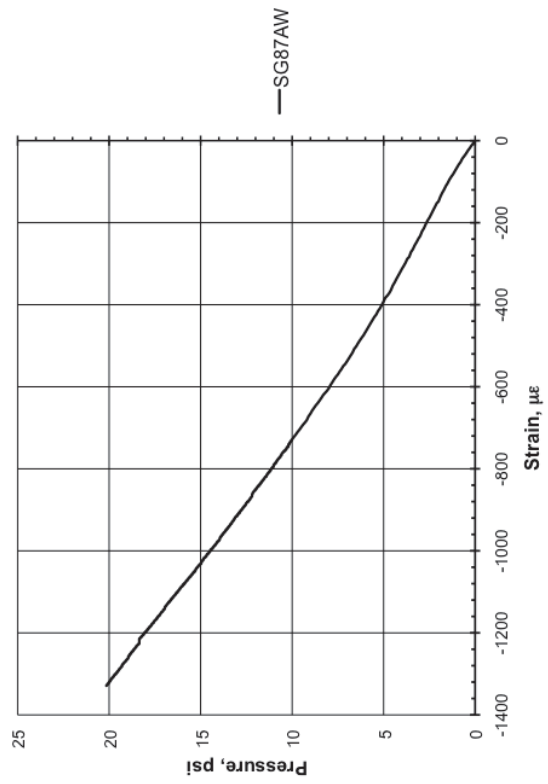


Figure D98. 2.2P test, strain gage SG87AW.

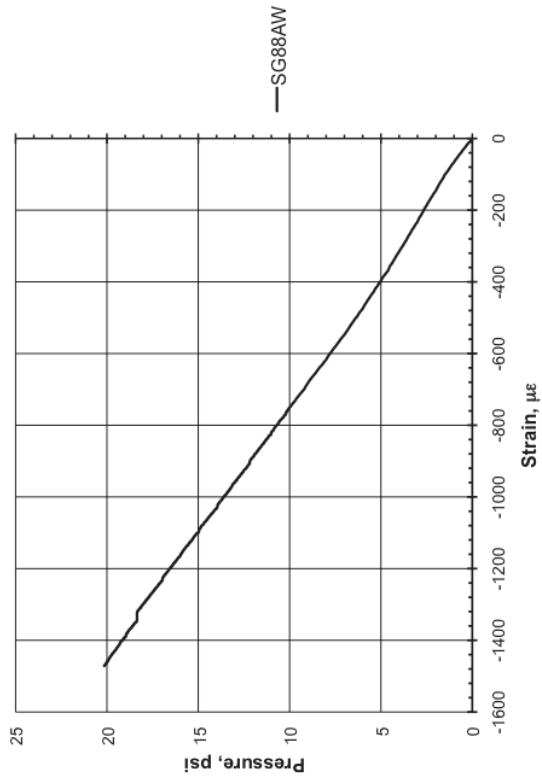


Figure D99. 2.2P test, strain gage SG88AW.

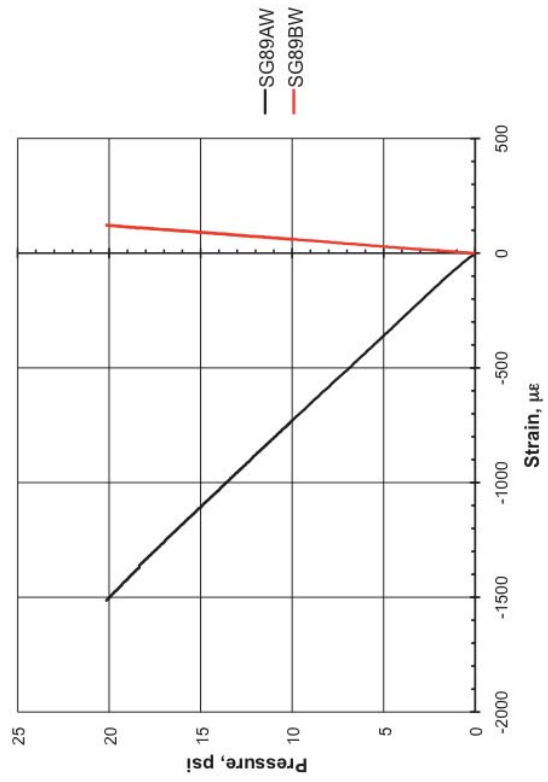


Figure D100. 2.2P test, strain gages SG89AW and SG89BW.

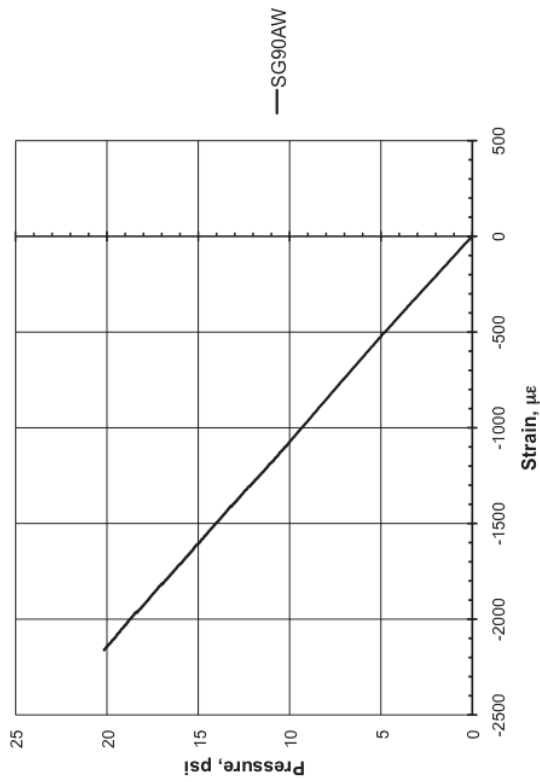


Figure D101. 2.2P test, strain gage SG90AW.

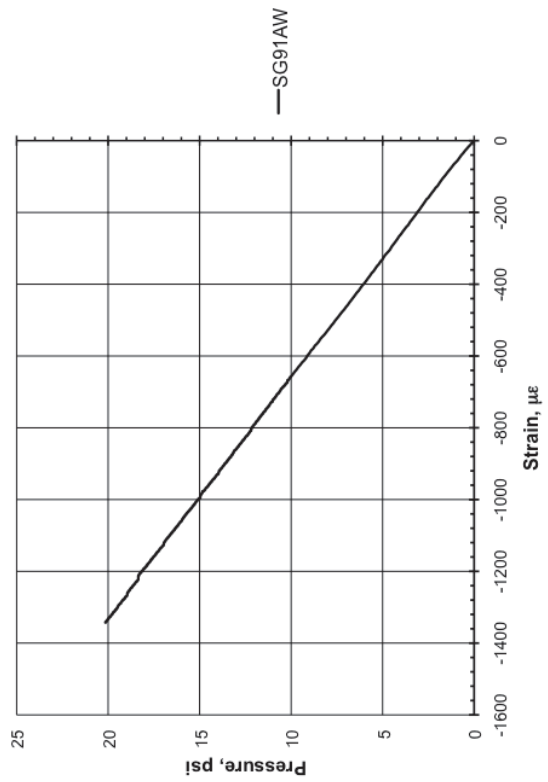


Figure D102. 2.2P test, strain gage SG91AW.

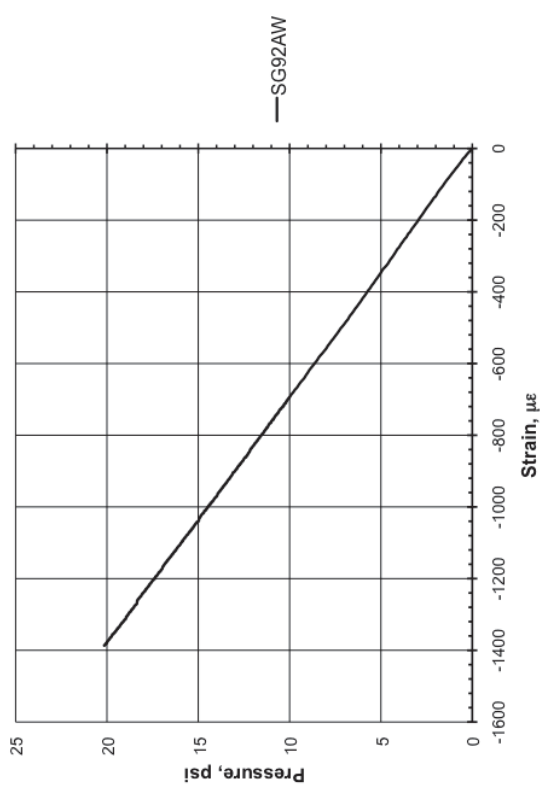


Figure D103. 2.2P test, strain gage SG92AW.

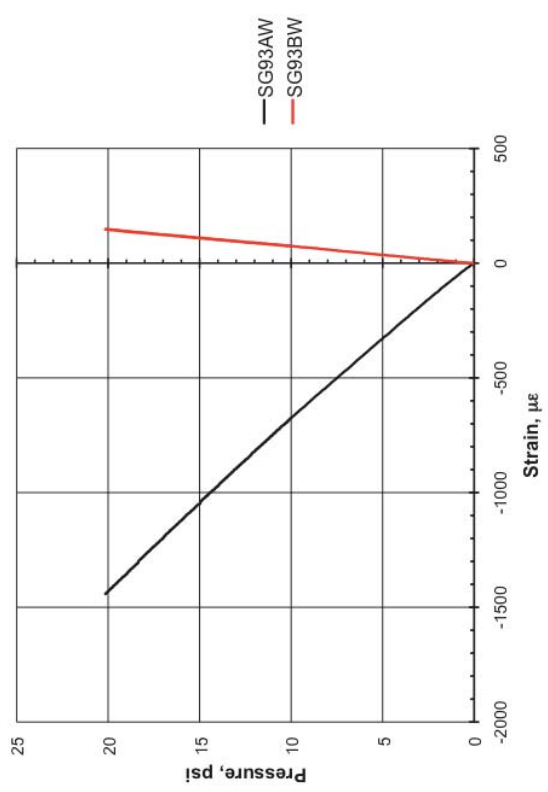


Figure D104. 2.2P test, strain gages SG93AW and SG93BW.



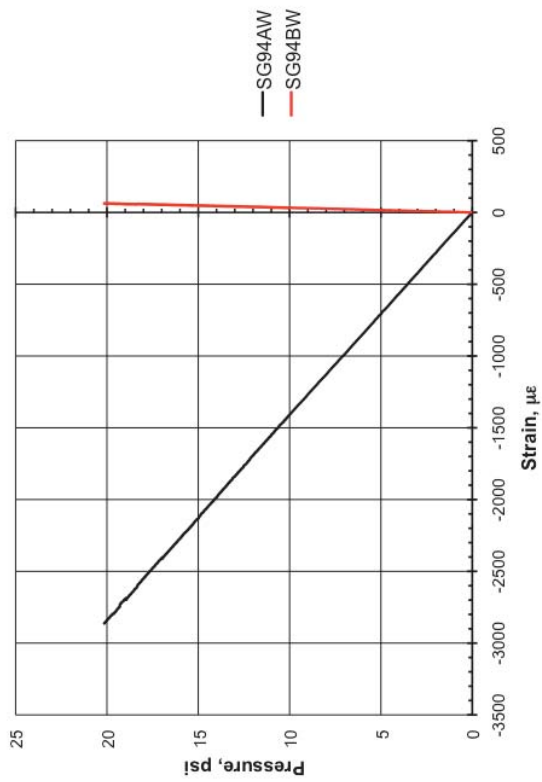


Figure D105. 2.2P test, strain gages SG94AW and SG94BW.

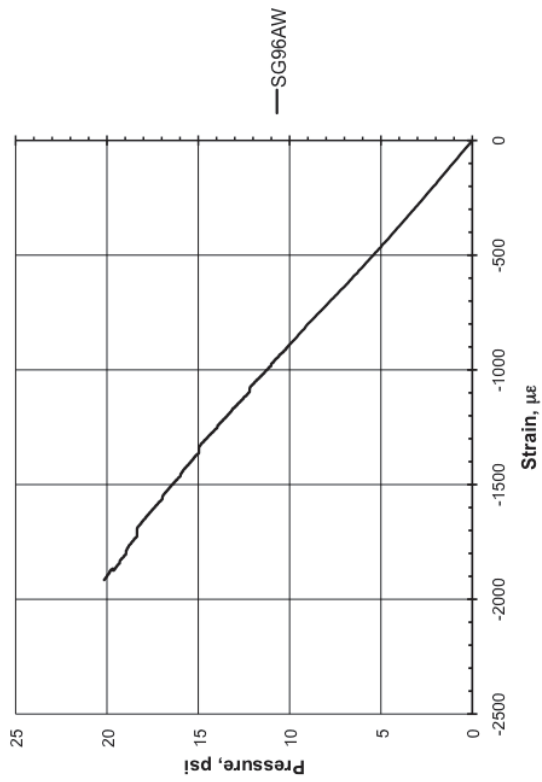


Figure D107. 2.2P test, strain gage SG96AW.

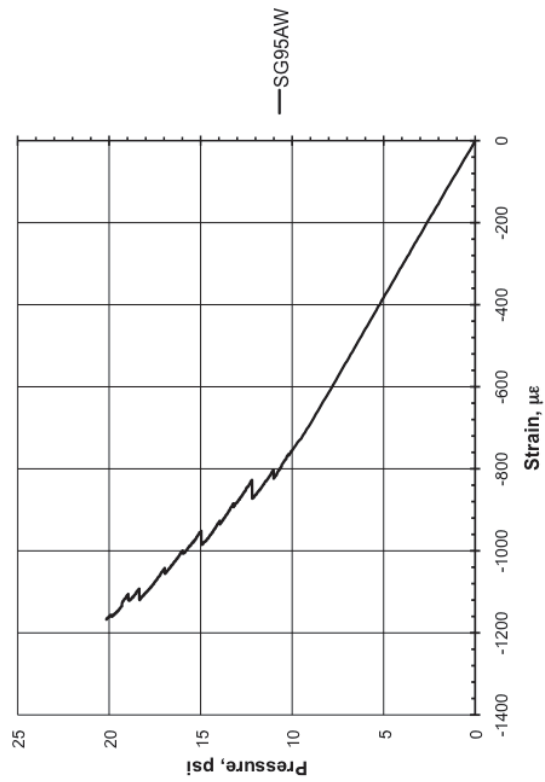


Figure D106. 2.2P test, strain gage SG95AW.

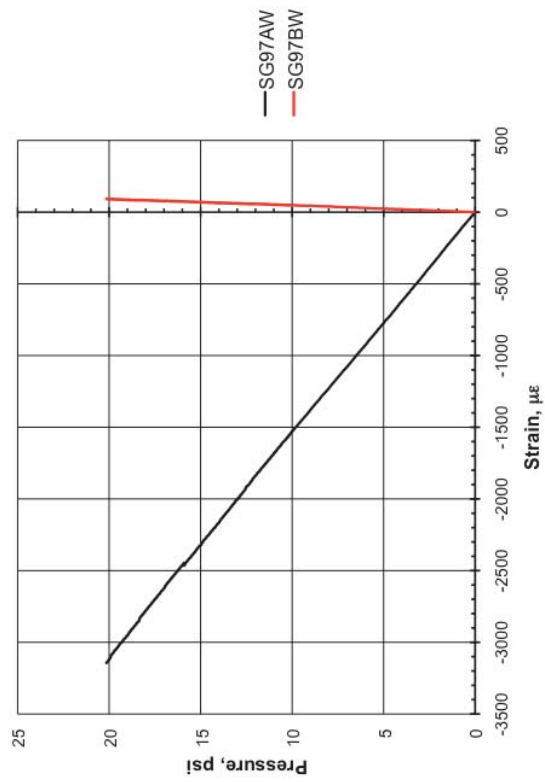


Figure D108. 2.2P test, strain gages SG97AW and SG97BW.

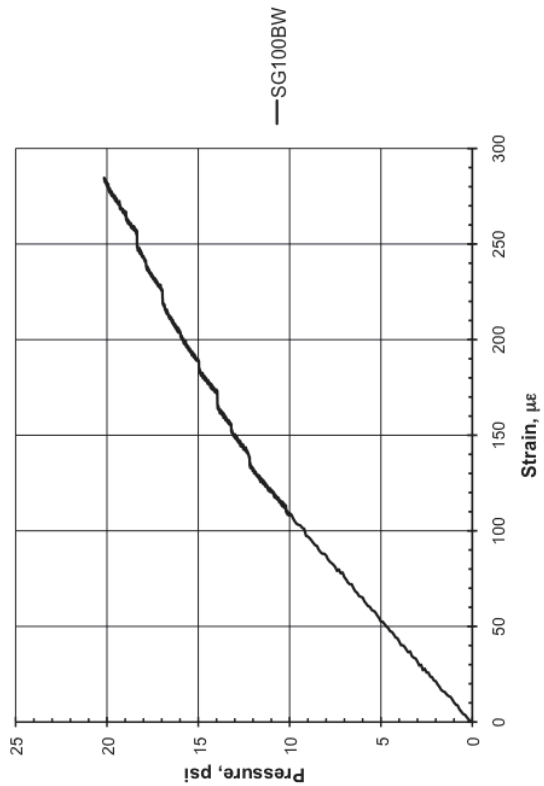


Figure D111. 2.2P test, strain gage SG100BW.

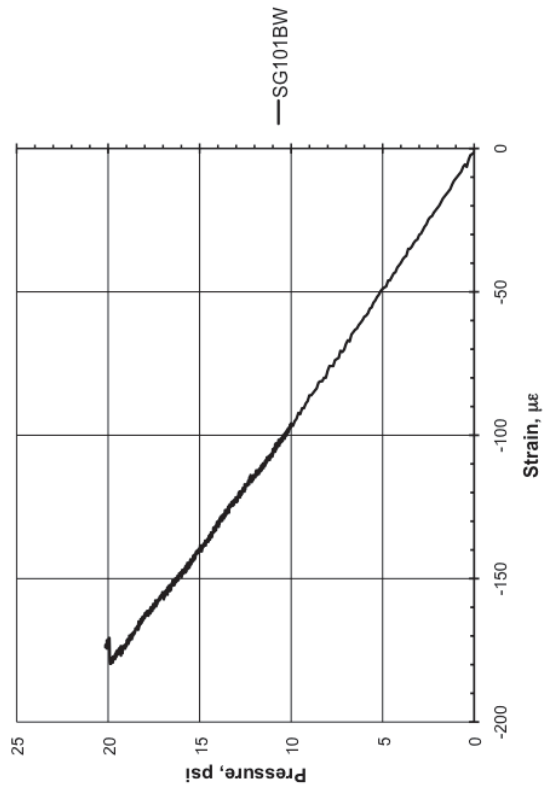


Figure D112. 2.2P test, strain gage SG101BW.

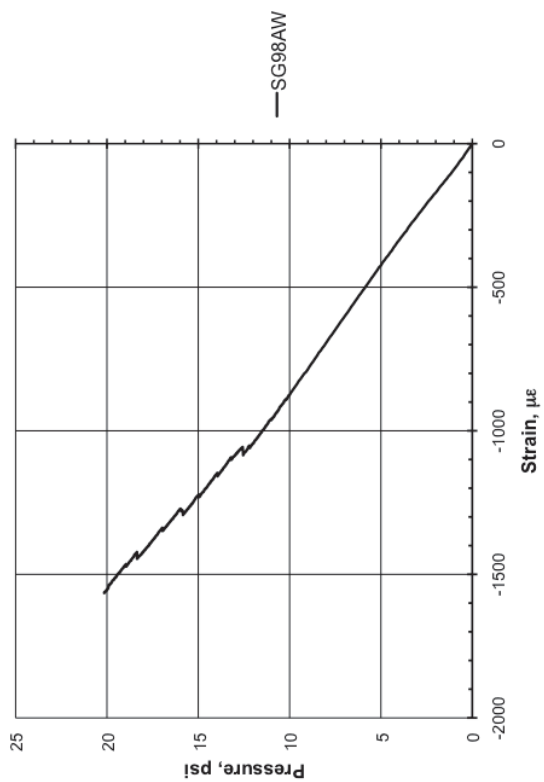


Figure D109. 2.2P test, strain gage SG98AW.

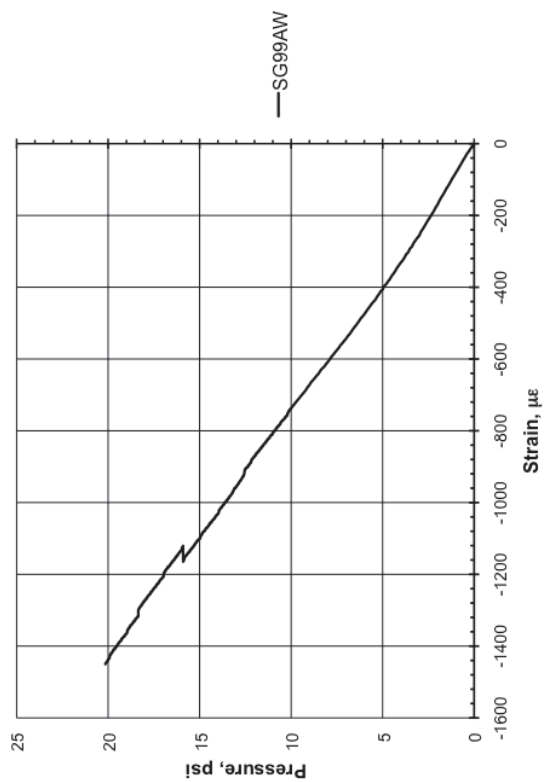


Figure D110. 2.2P test, strain gage SG99AW.

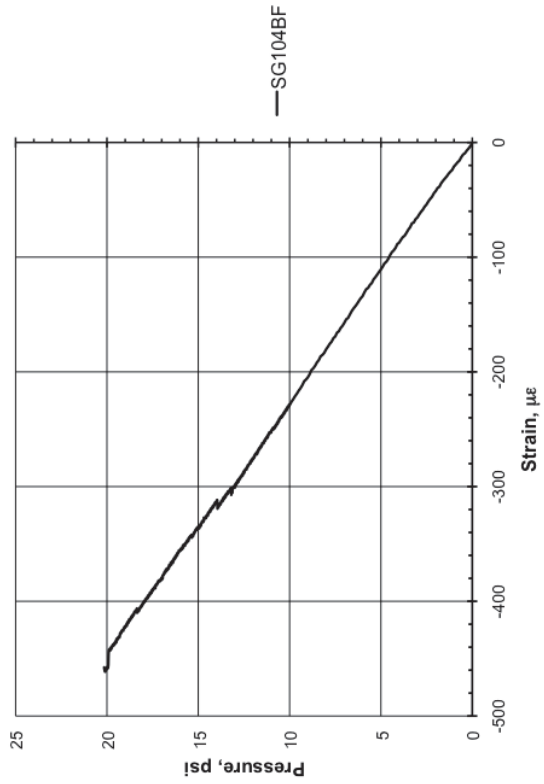


Figure D115. 2.2P test, strain gage SG104BF.

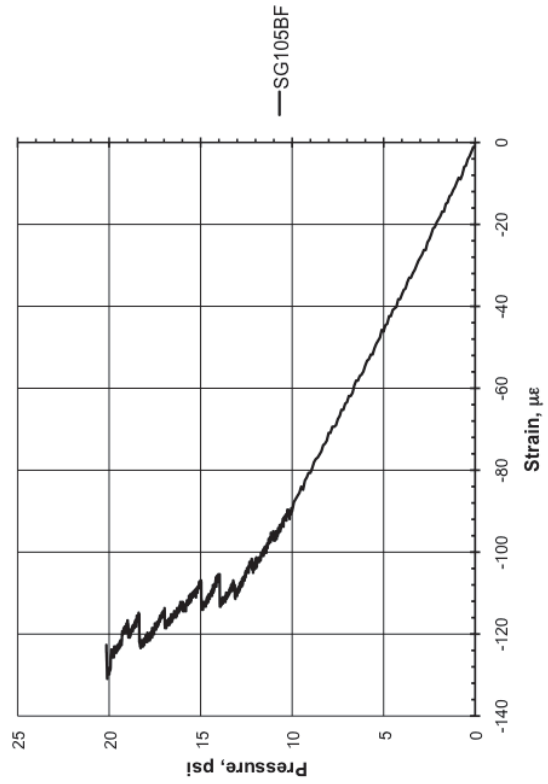


Figure D116. 2.2P test, strain gage SG105BF.

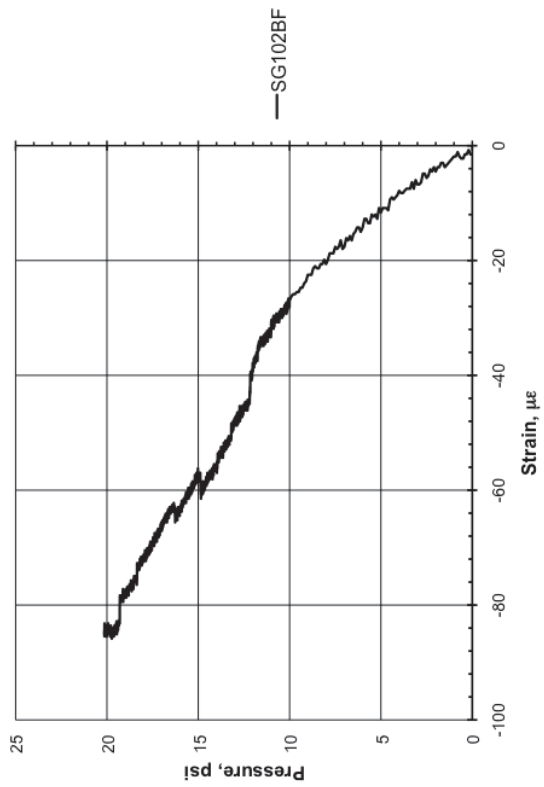


Figure D113. 2.2P test, strain gage SG102BF.

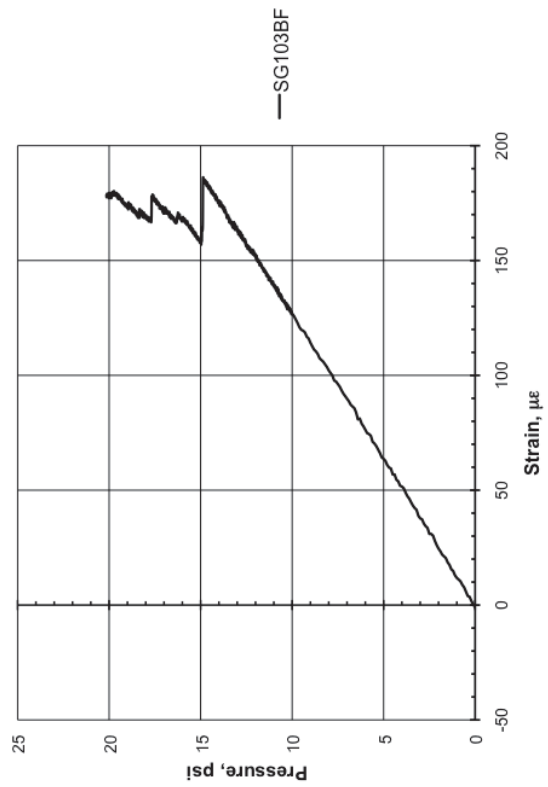


Figure D114. 2.2P test, strain gage SG103BF.

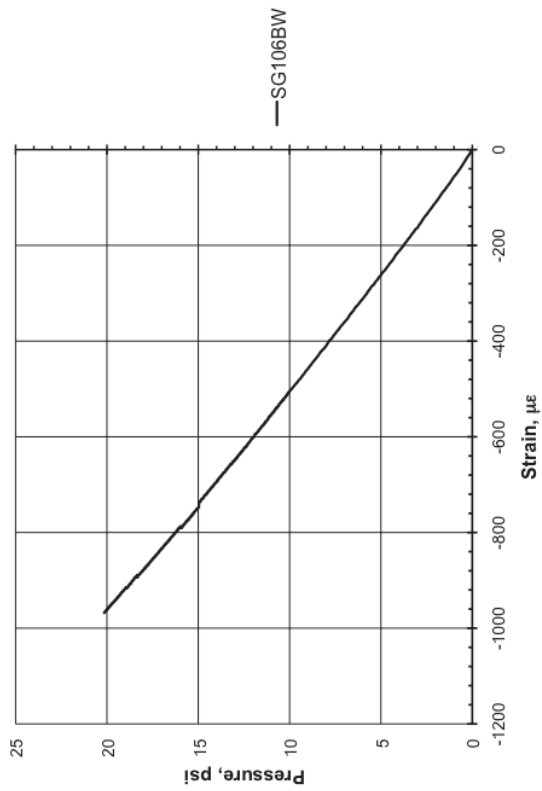


Figure D117. 2.2P test, strain gage SG106BW.

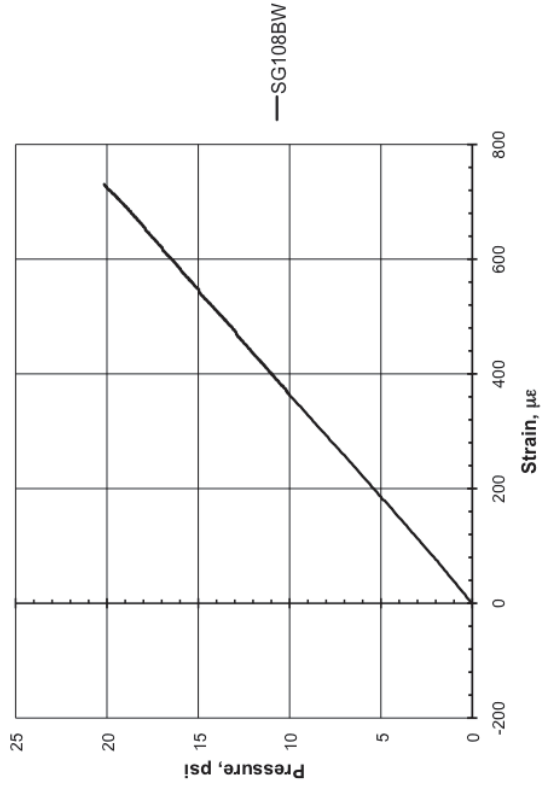


Figure D119. 2.2P test, strain gage SG108BW.

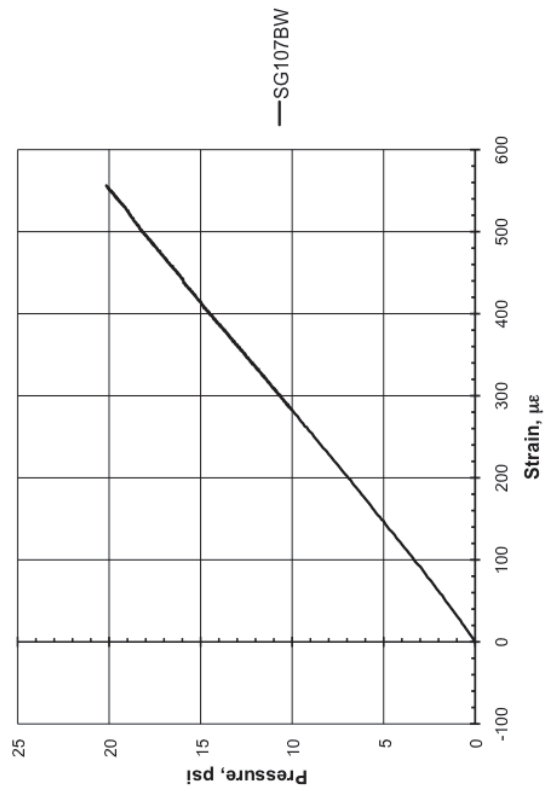


Figure D118. 2.2P test, strain gage SG107BW.

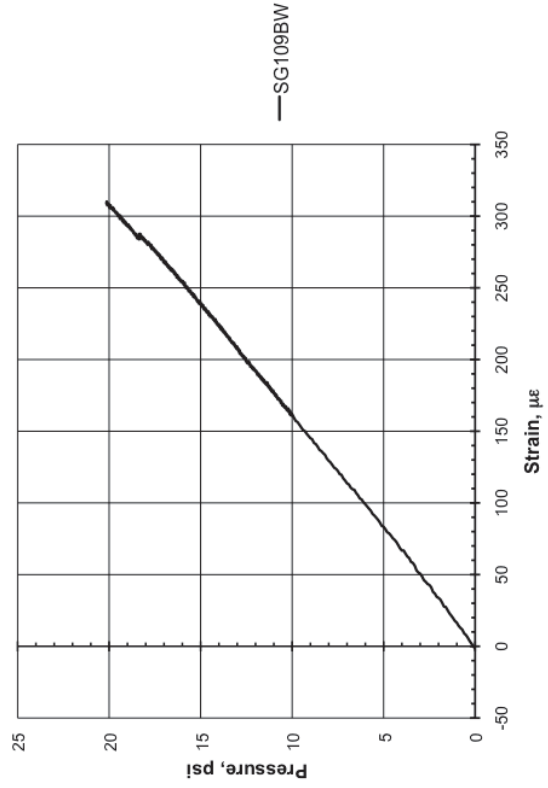


Figure D120. 2.2P test, strain gage SG109BW.

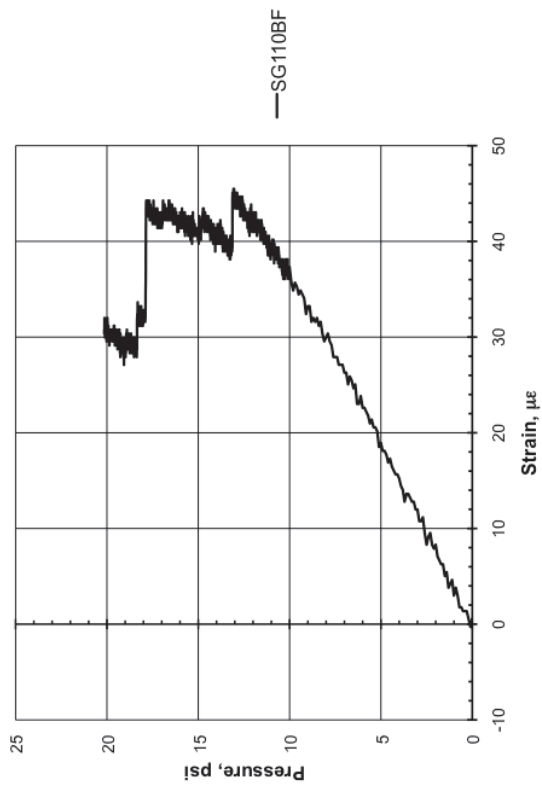


Figure D121. 2.2P test, strain gage SG110BF.

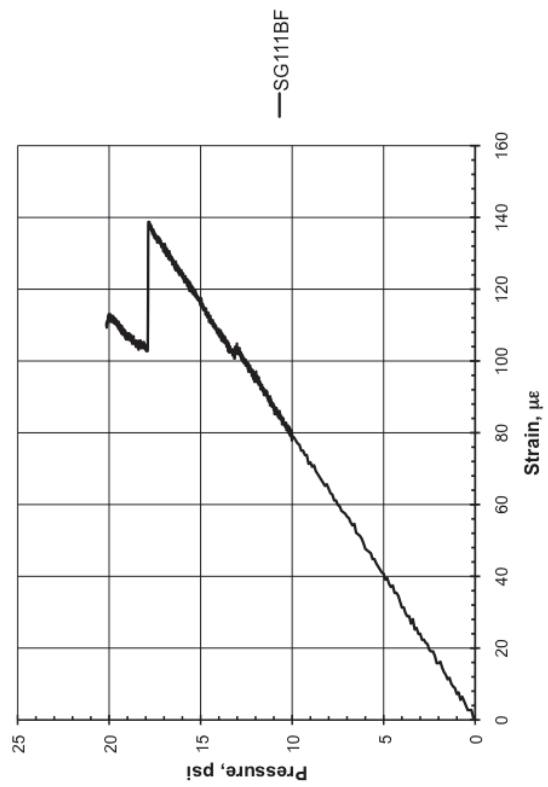


Figure D122. 2.2P test, strain gage SG111BF.

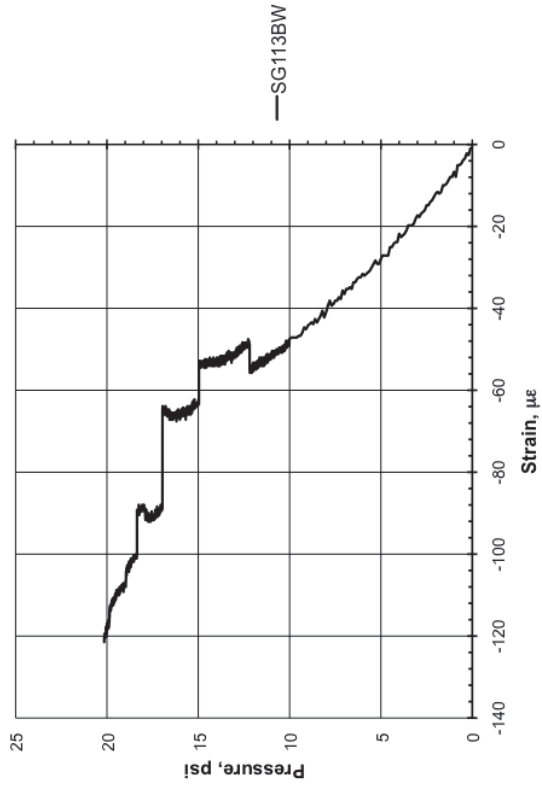


Figure D123. 2.2P test, strain gage SG113BW.

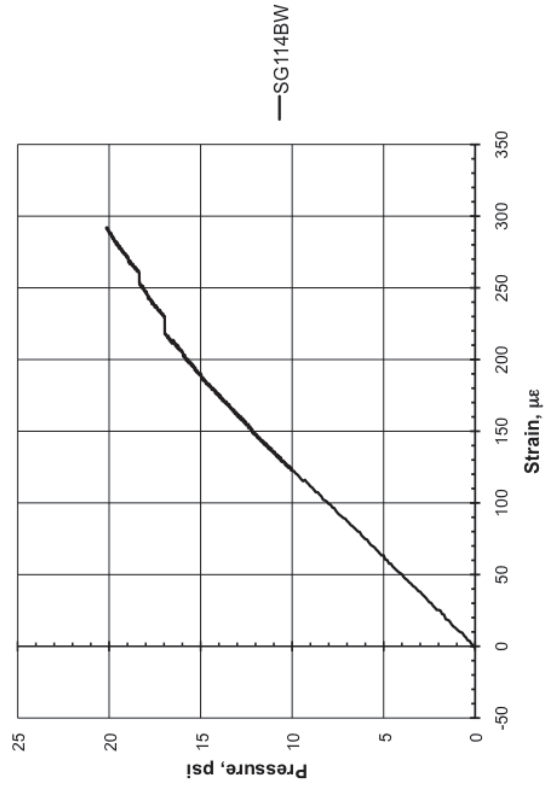


Figure D124. 2.2P test, strain gage SG114BW.

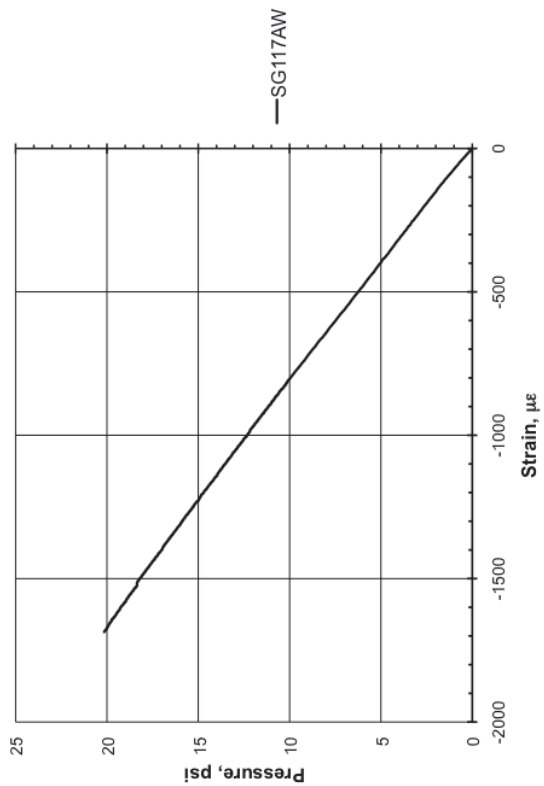


Figure D127. 2.2P test, strain gage SG117AW.

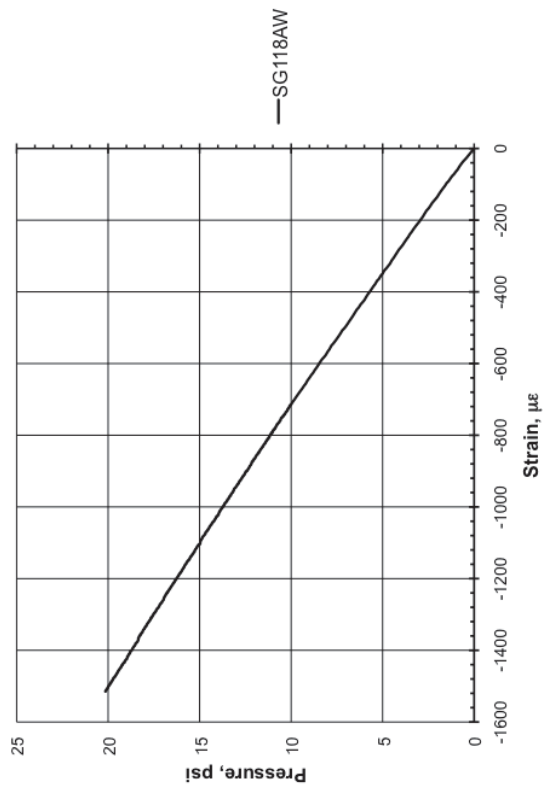


Figure D128. 2.2P test, strain gage SG118AW.

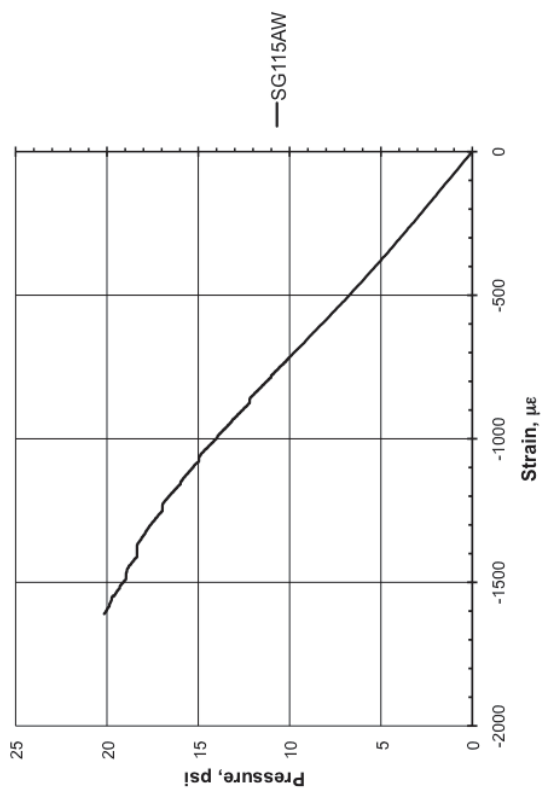


Figure D125. 2.2P test, strain gage SG115AW.

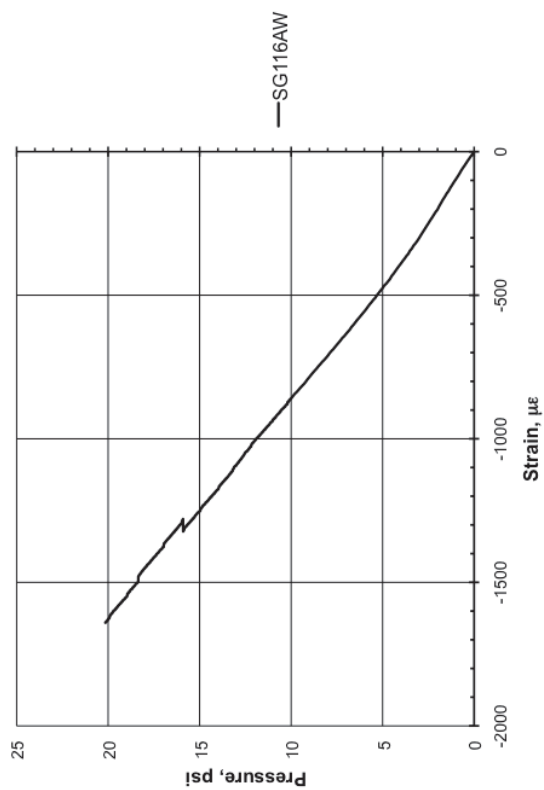
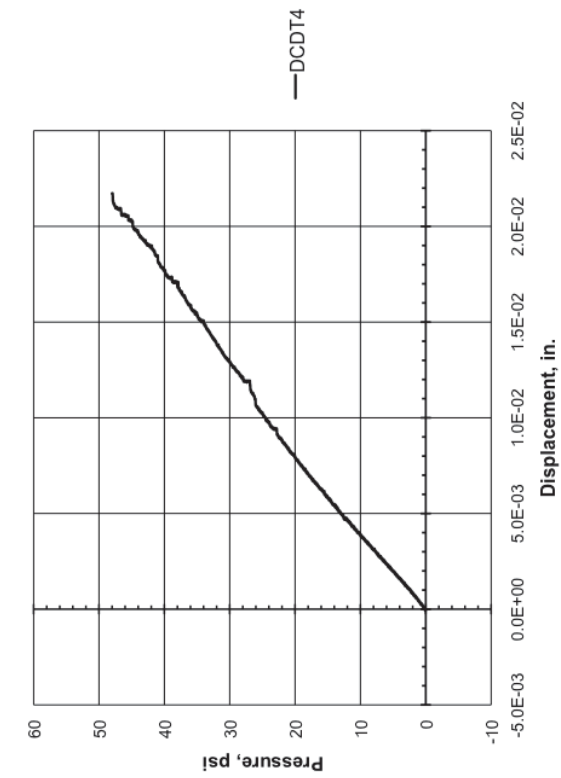
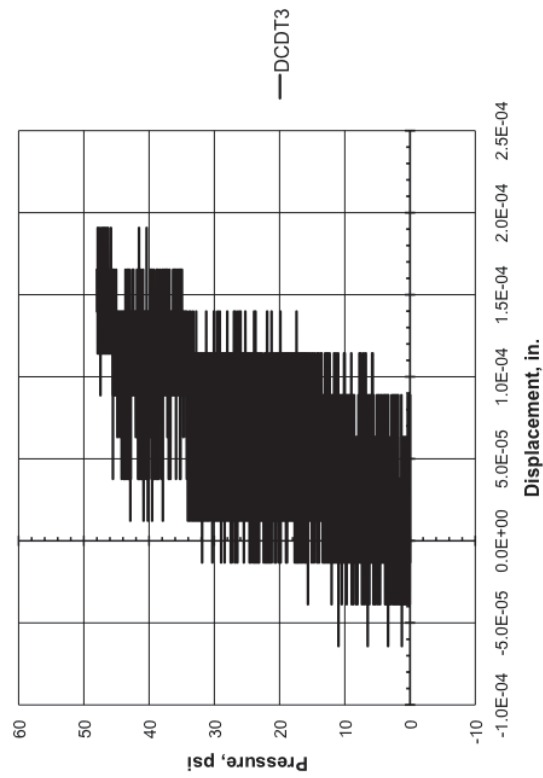
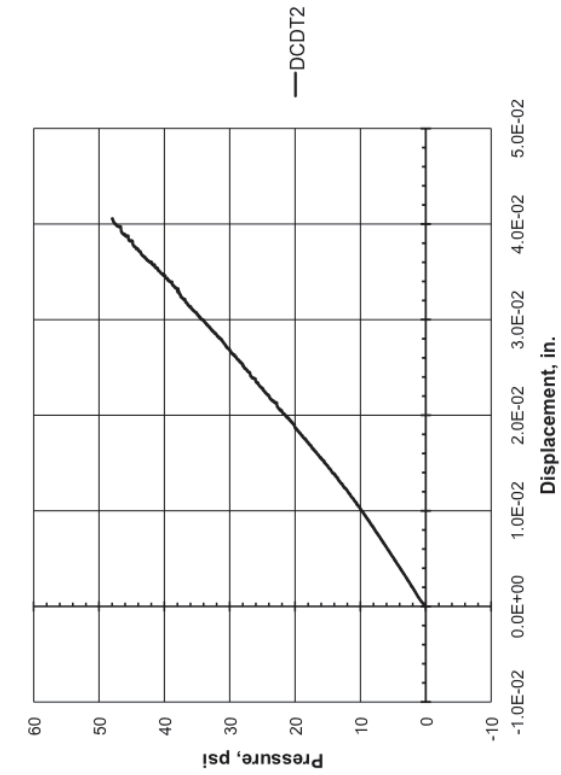
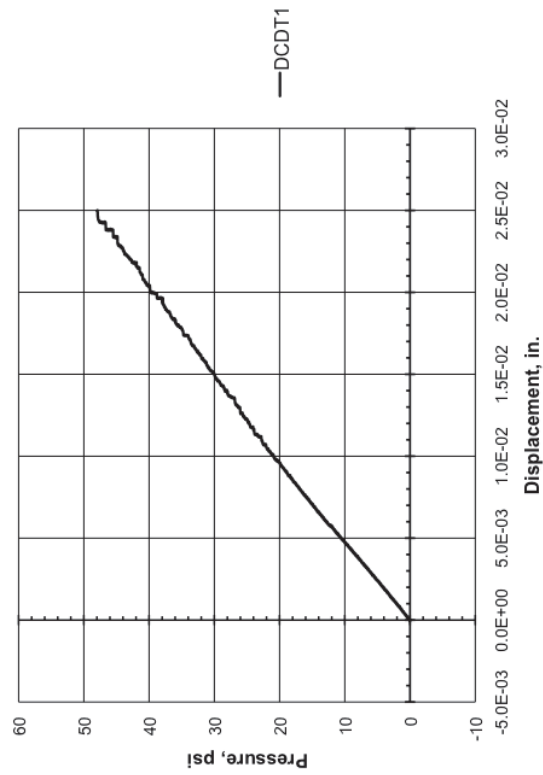


Figure D126. 2.2P test, strain gage SG116AW.

**Appendix E:**  
**Test to Failure DCDT and Strain Gage Plots**





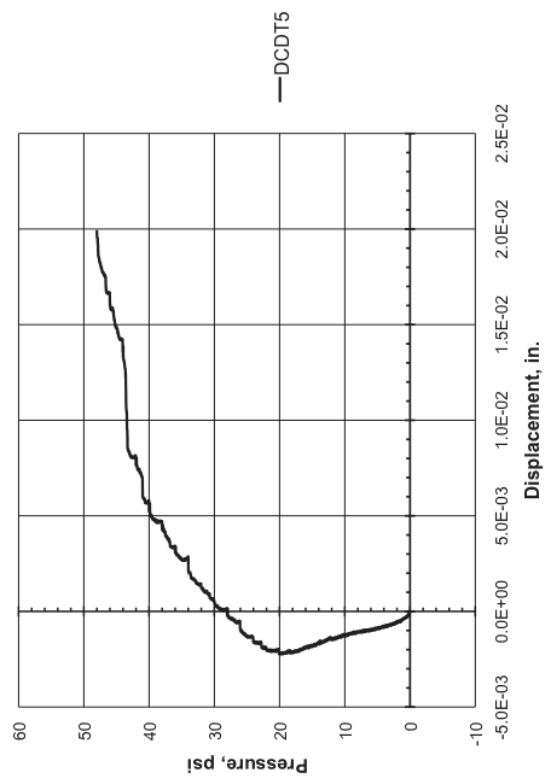


Figure E5. Test to failure, DCDT5.

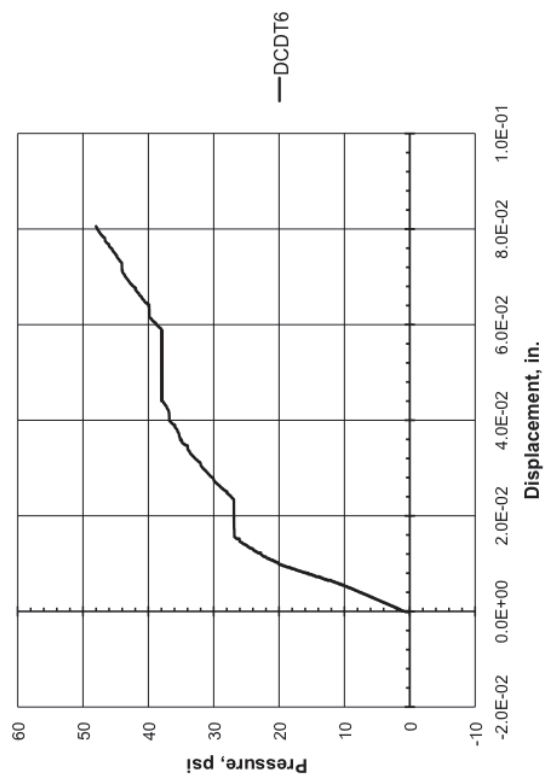


Figure E6. Test to failure, DCDT6.

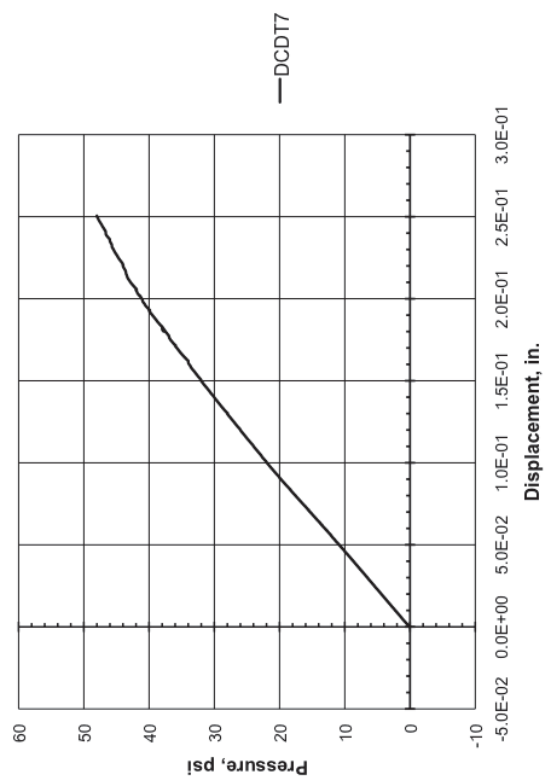


Figure E7. Test to failure, DCDT7.

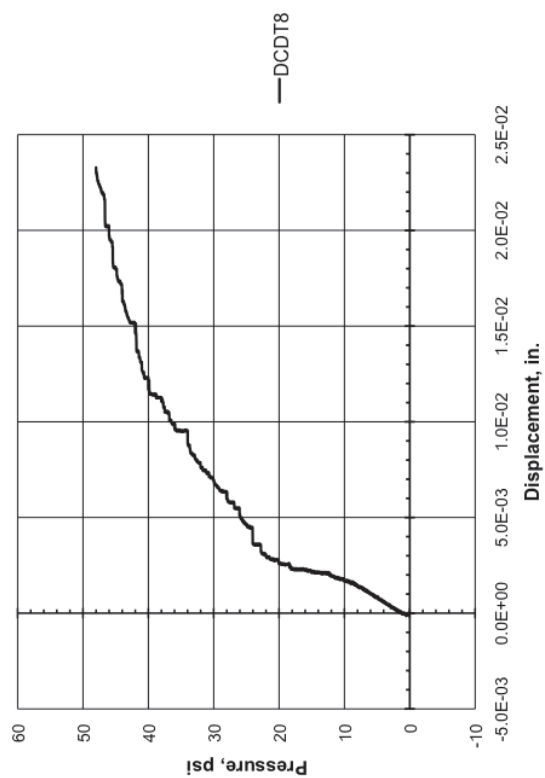
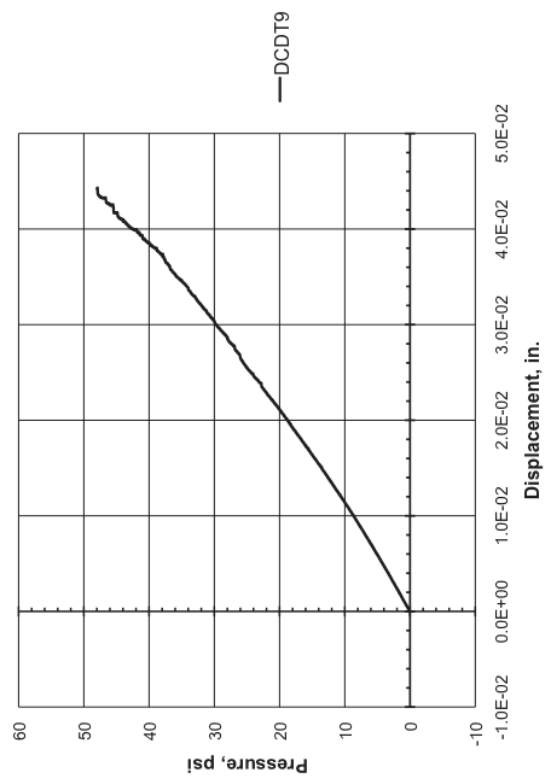
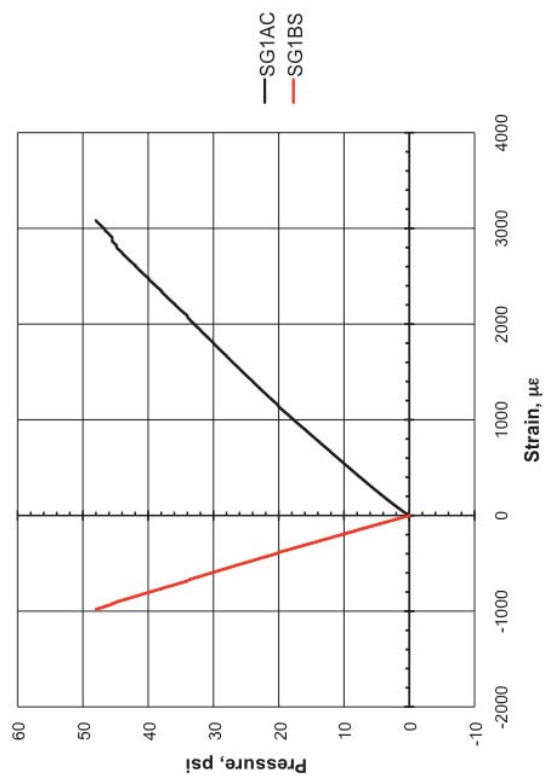
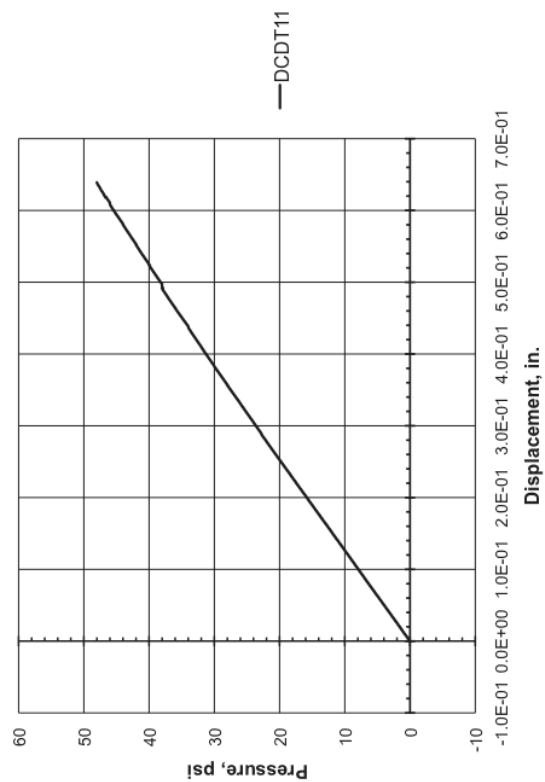
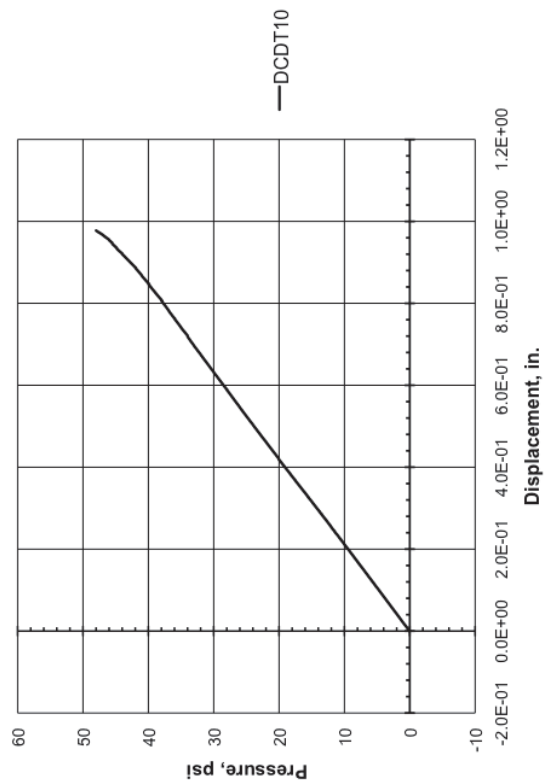


Figure E8. Test to failure, DCDT8.



E4



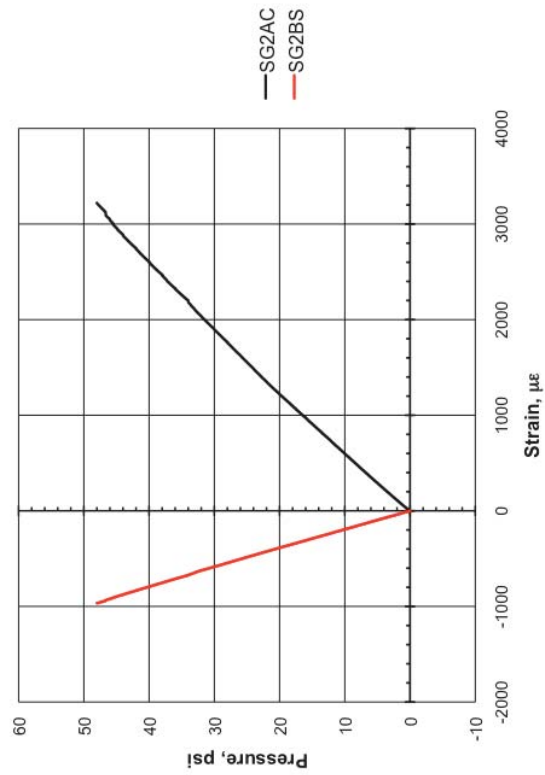


Figure E13. Test to failure, strain gages SG2AC and SG2BS.

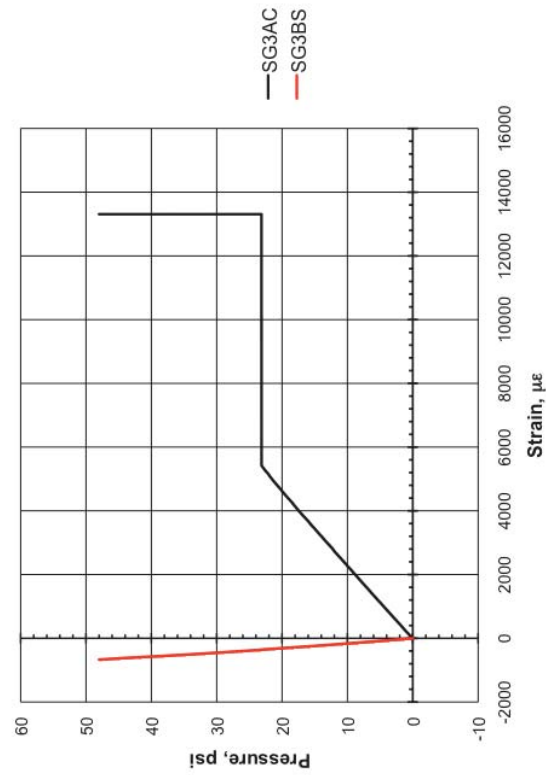


Figure E14. Test to failure, strain gages SG3AC and SG3BS.

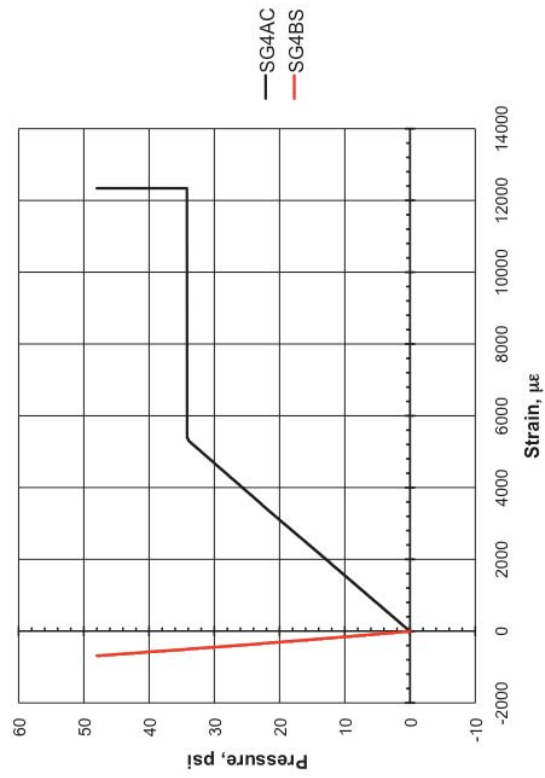


Figure E15. Test to failure, strain gages SG4AC and SG4BS.

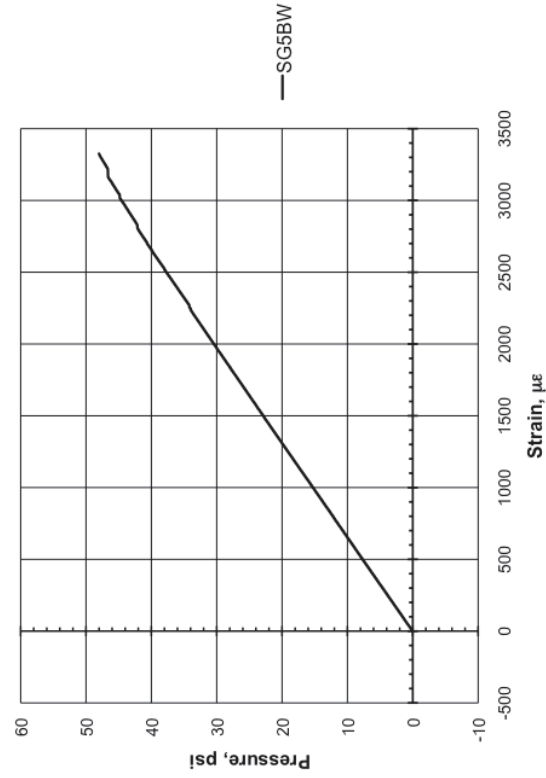


Figure E16. Test to failure, strain gage SG5BW.

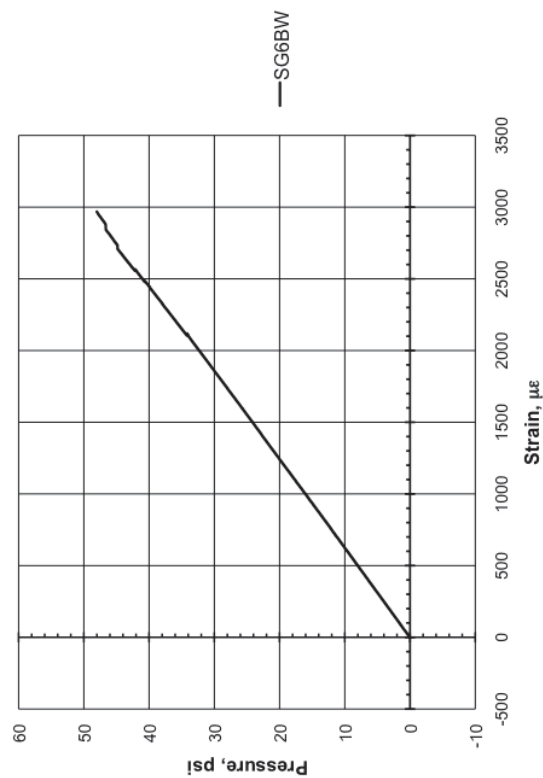


Figure E17. Test to failure, strain gage SG6BW.

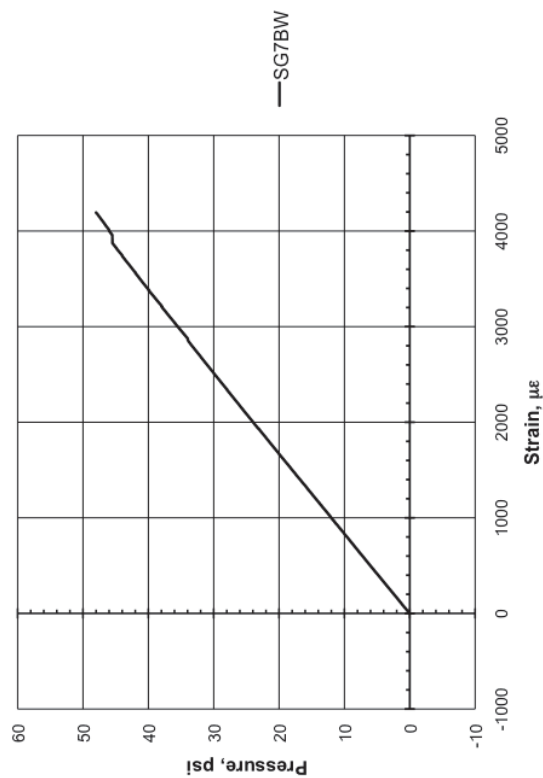


Figure E18. Test to failure, strain gage SG7BW.

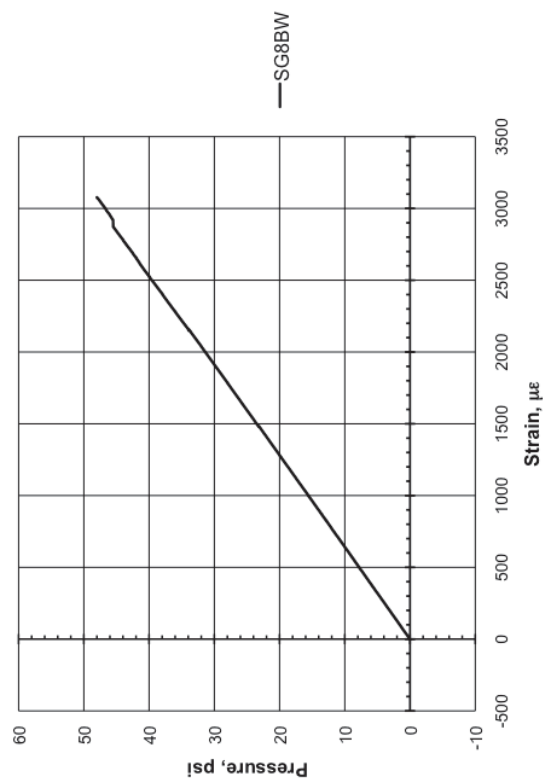


Figure E19. Test to failure, strain gage SG8BW.

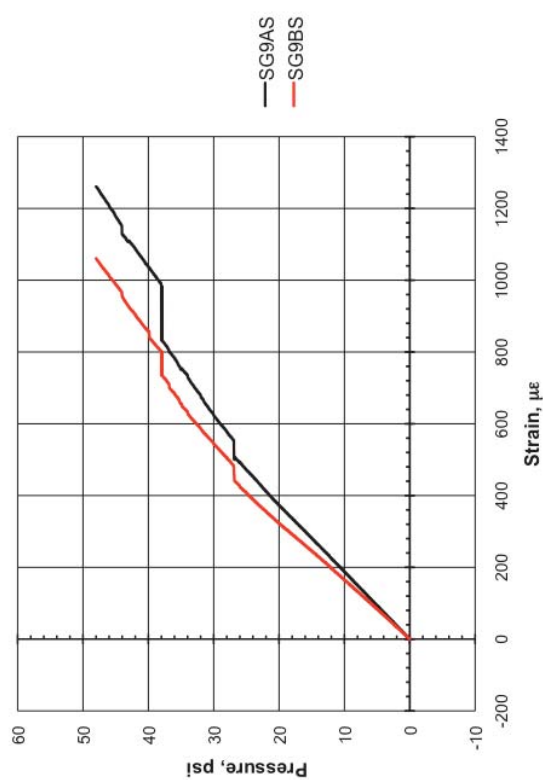


Figure E20. Test to failure, strain gages SG9AS and SG9BS.

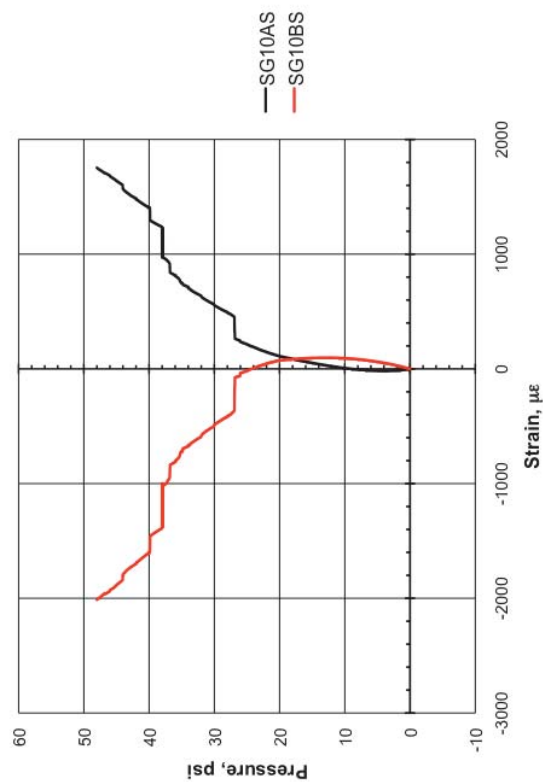


Figure E21. Test to failure, strain gages SG10AS and SG10BS.

E7

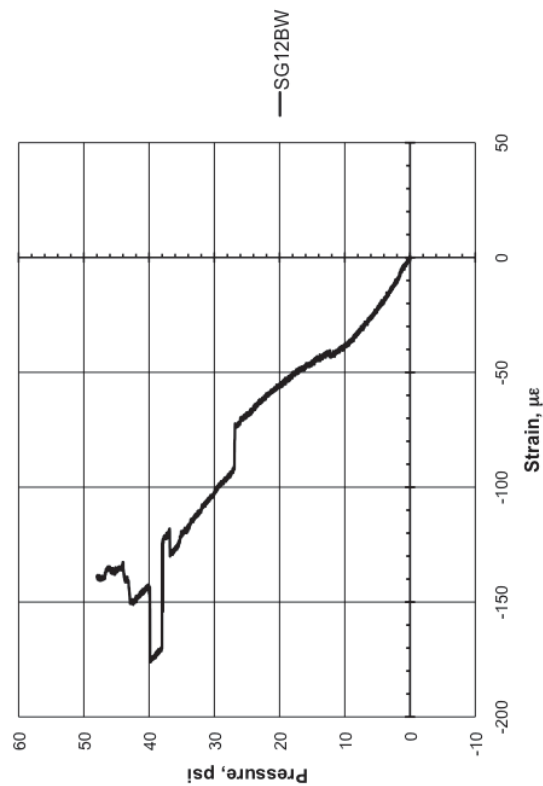


Figure E23. Test to failure, strain gage SG12BW.

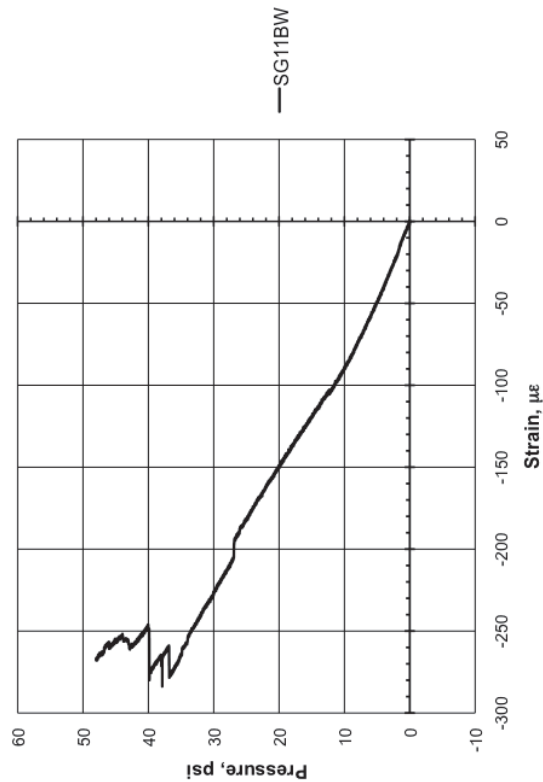


Figure E22. Test to failure, strain gage SG11BW.

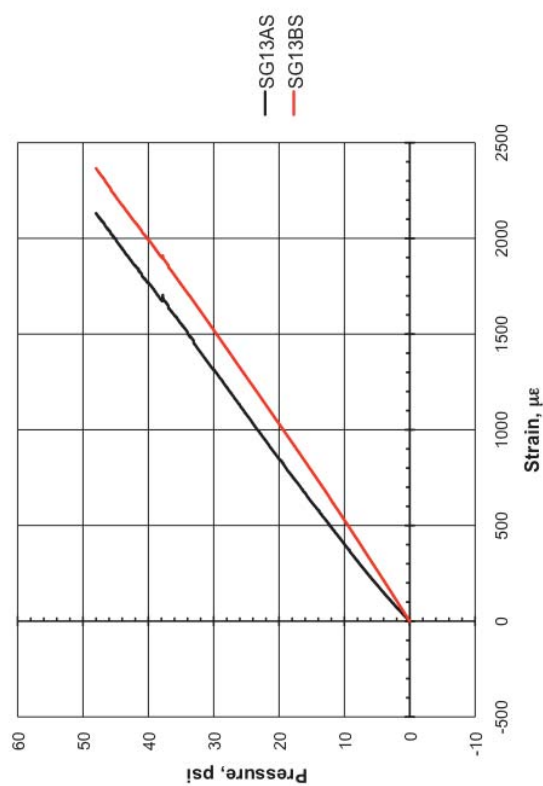


Figure E24. Test to failure, strain gages SG13AS and SG13BS.

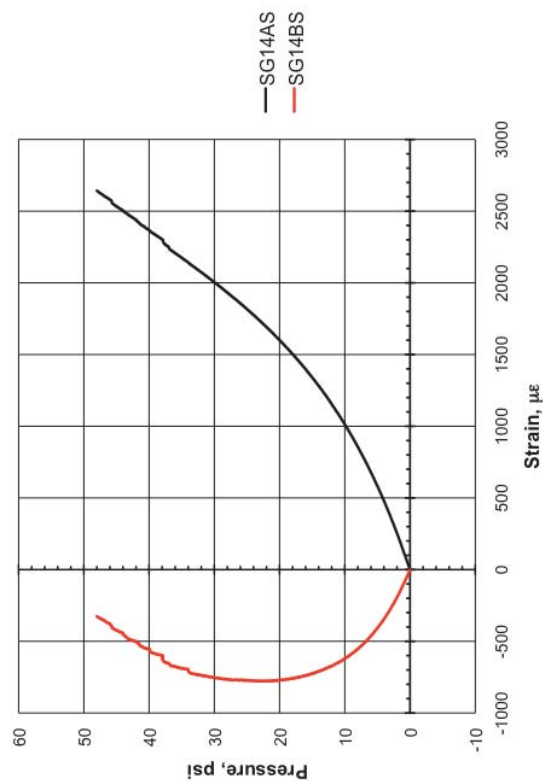


Figure E25. Test to failure, strain gages SG14AS and SG14BS.

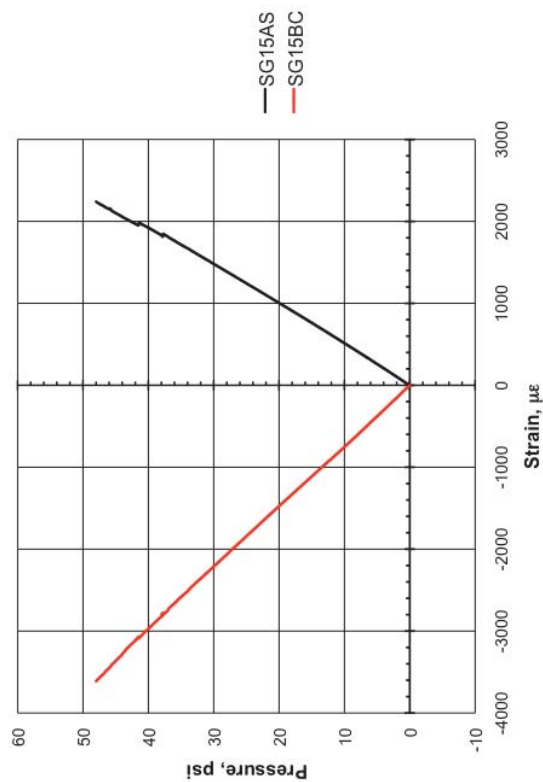


Figure E26. Test to failure, strain gages SG15AS and SG15BC.

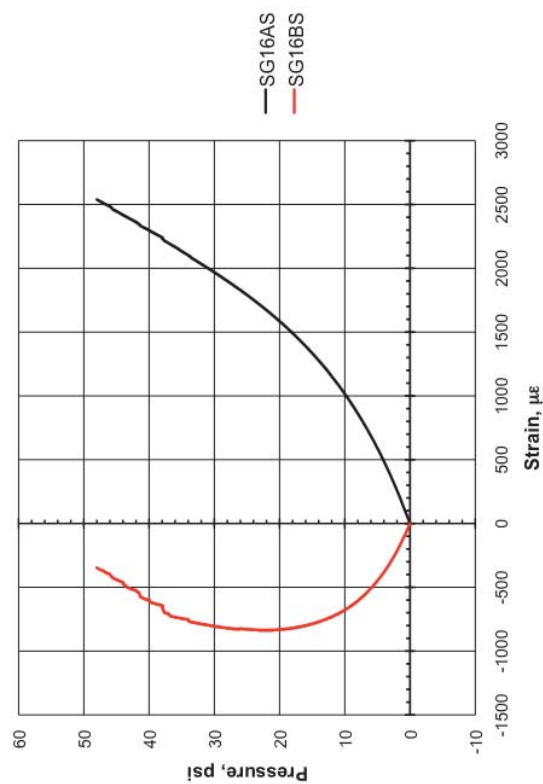


Figure E27. Test to failure, strain gages SG16AS and SG16BS.

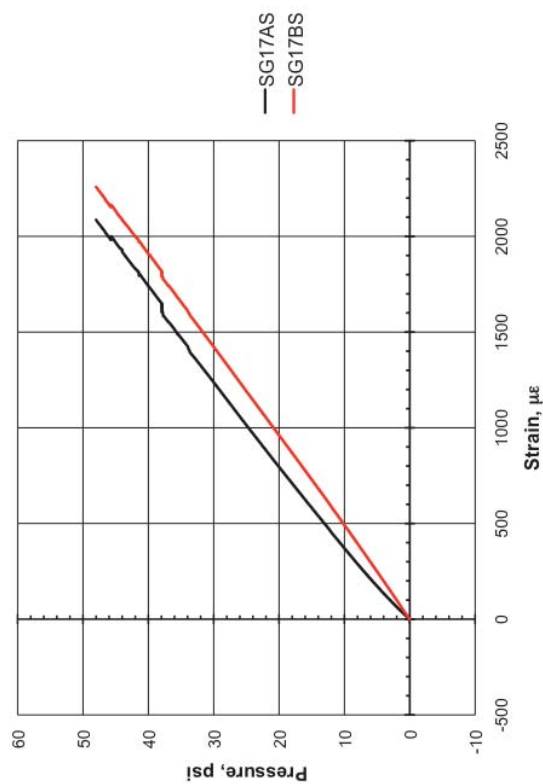


Figure E28. Test to failure, strain gages SG17AS and 17BS.

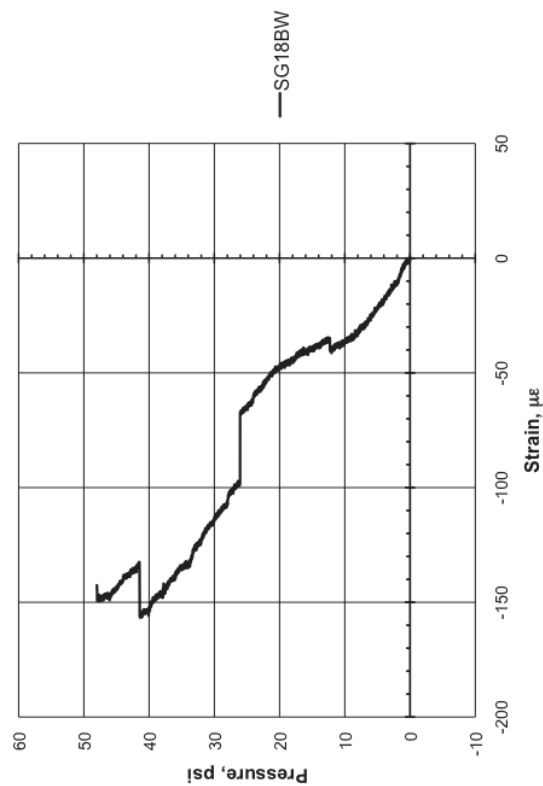


Figure E29. Test to failure, strain gage SG18BW.

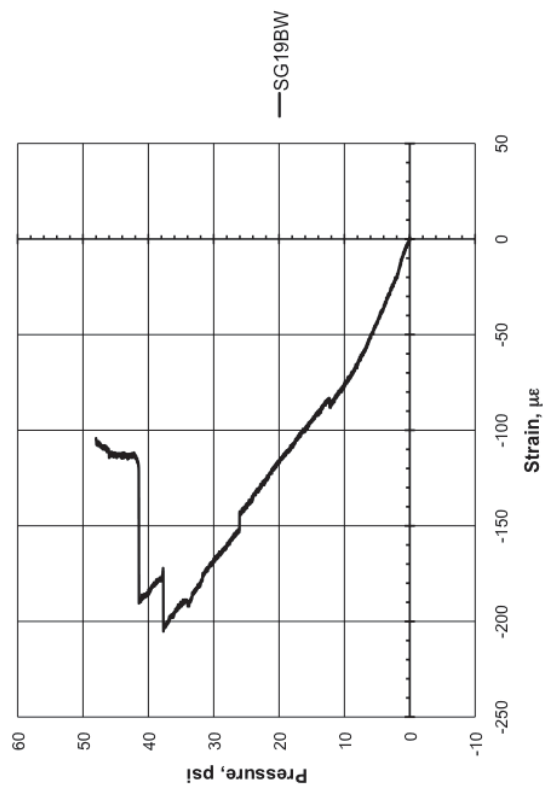


Figure E30. Test to failure, strain gage SG19BW.

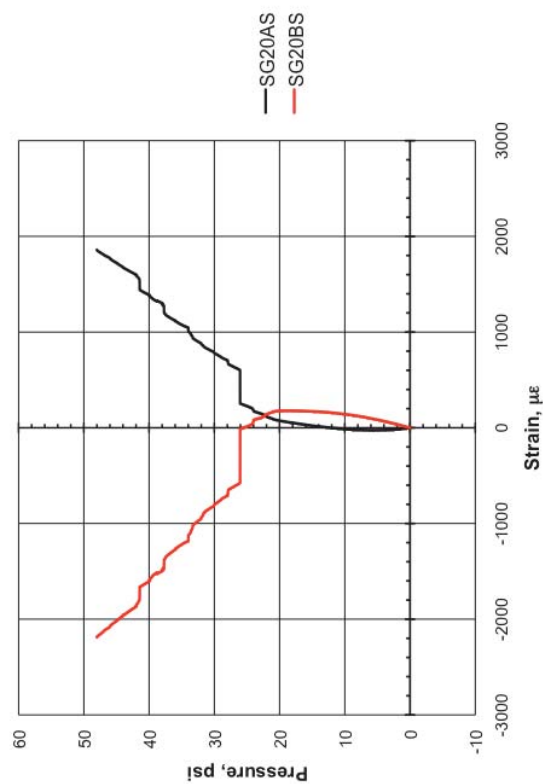


Figure E31. Test to failure, strain gages SG20AS and SG20BS.

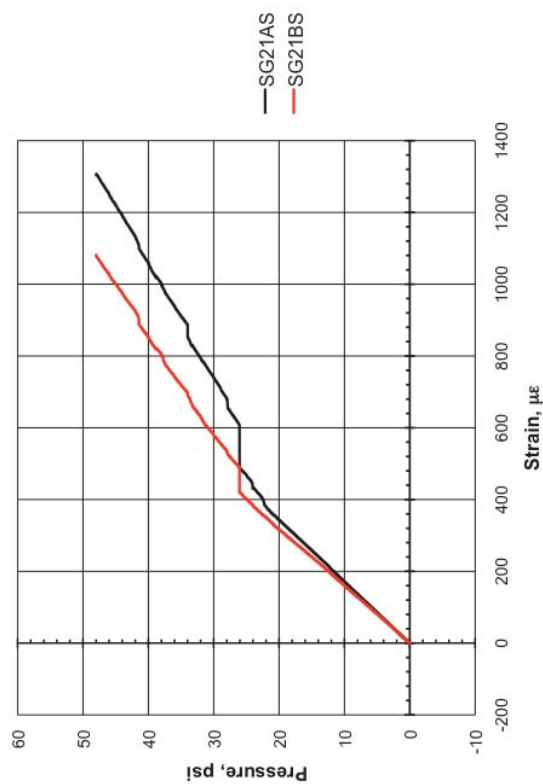


Figure E32. Test to failure, strain gages SG21AS and SG21BS.

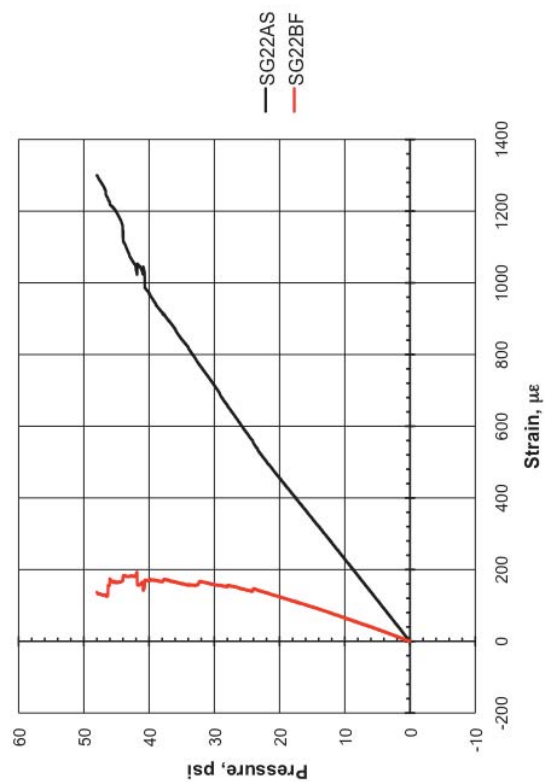


Figure E33. Test to failure, strain gages SG22AS and SG22BF.

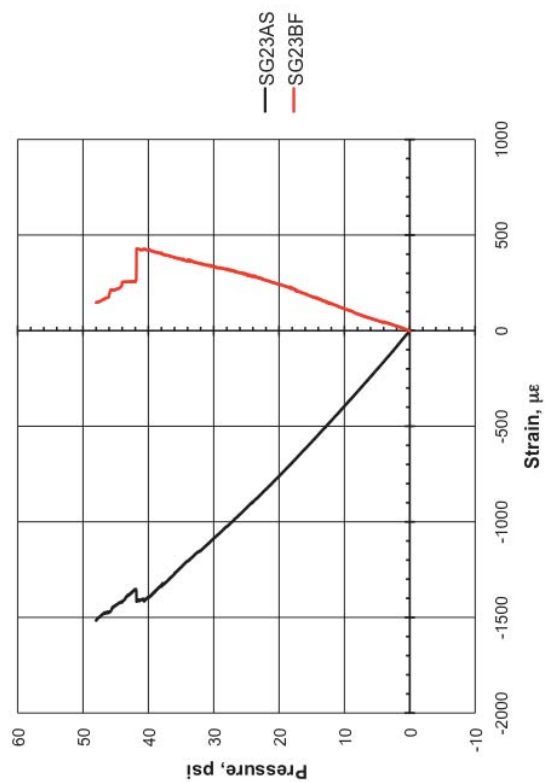


Figure E34. Test to failure, strain gages SG23AS and SG23BF.

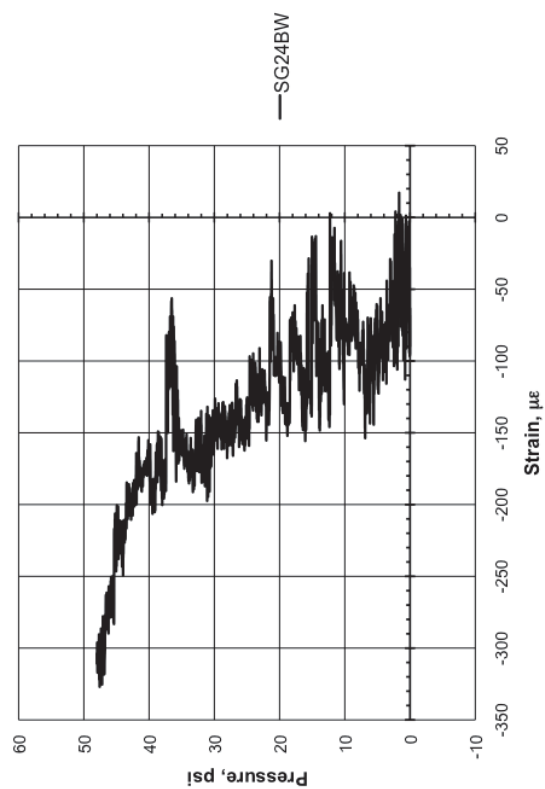


Figure E35. Test to failure, strain gage SG24BW.

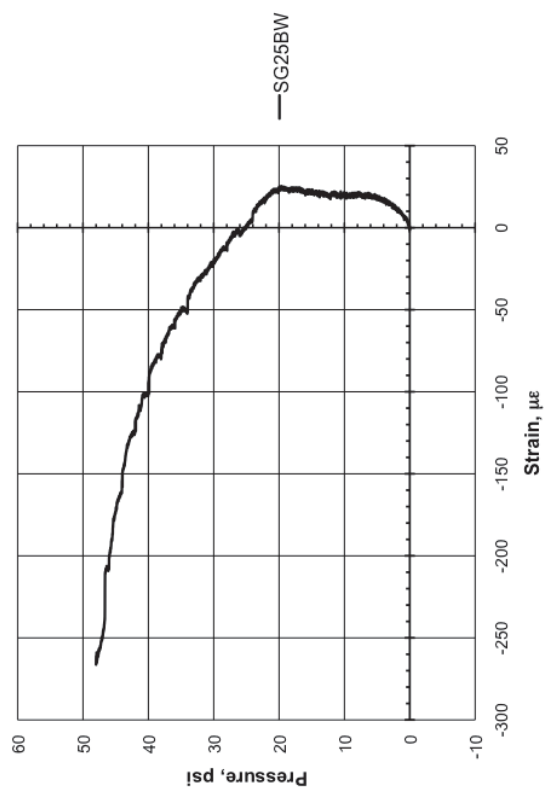


Figure E36. Test to failure, strain gage SG25BW.



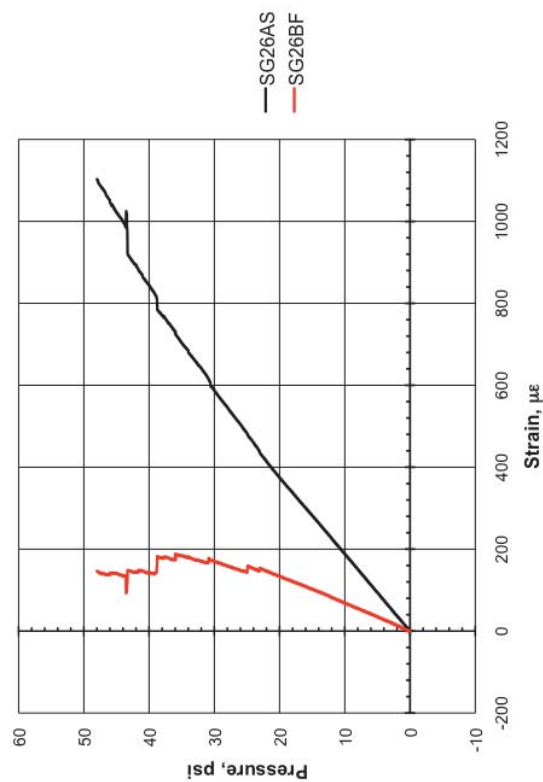


Figure E37. Test to failure, strain gages SG26AS and SG26BF.

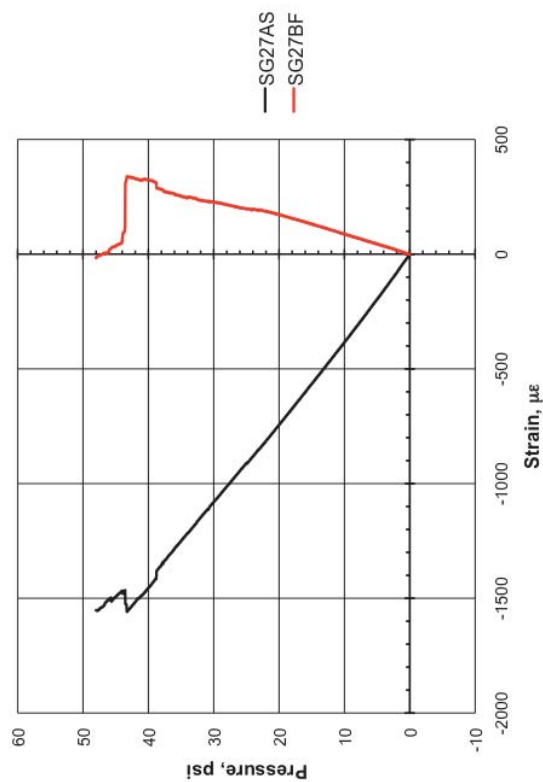


Figure E38. Test to failure, strain gages SG27AS and SG27BF.

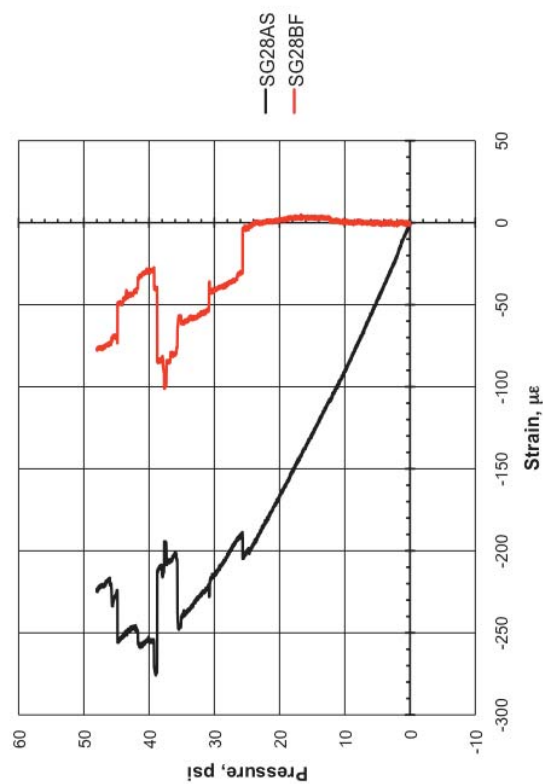


Figure E39. Test to failure, strain gages SG28AS and SG28BF.

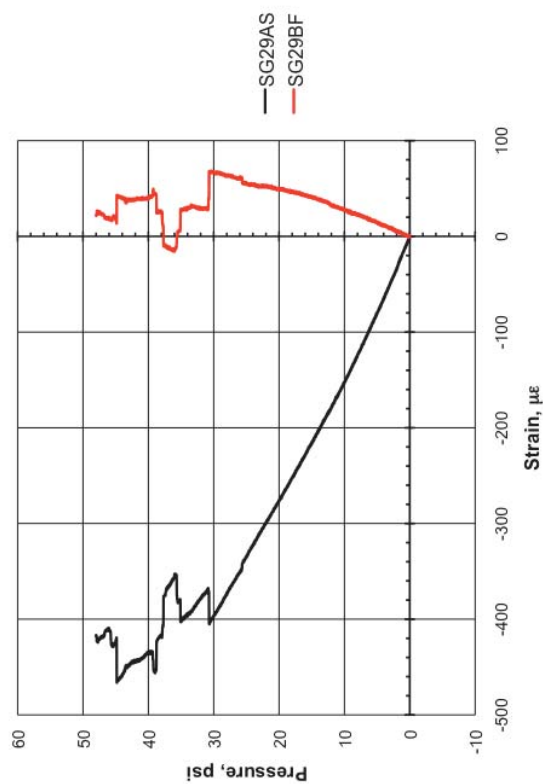
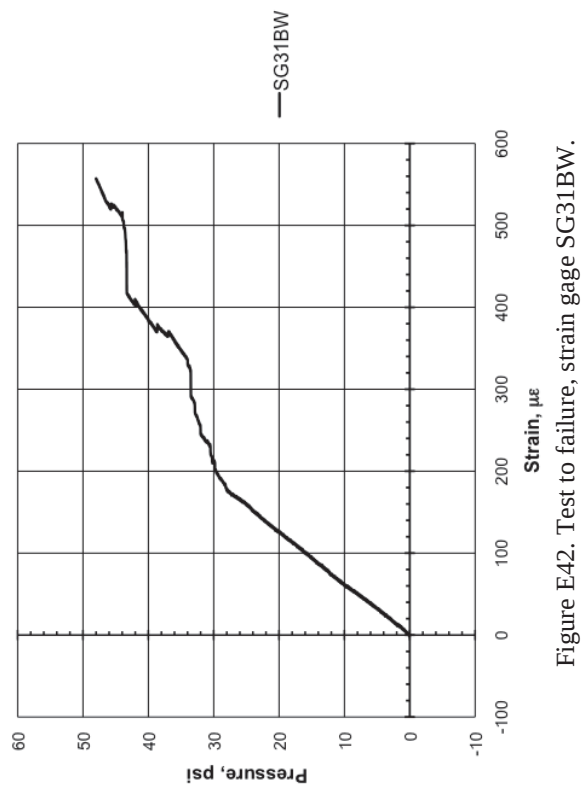
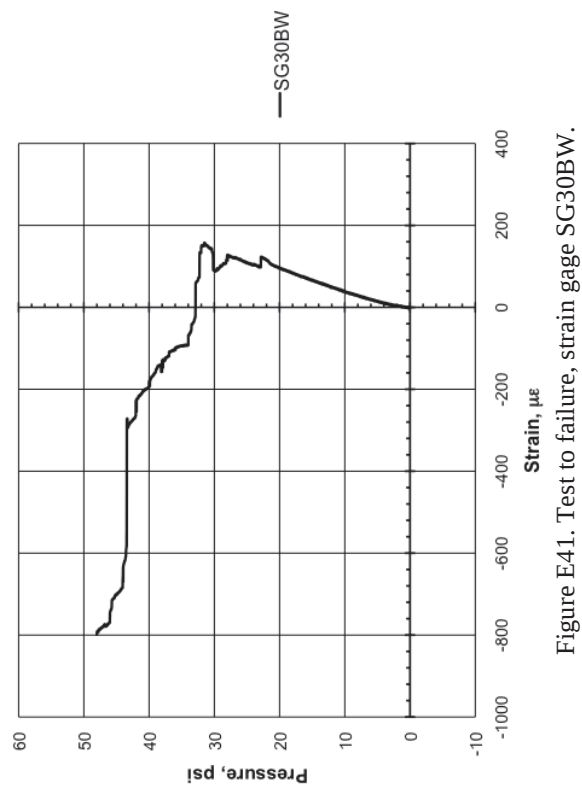
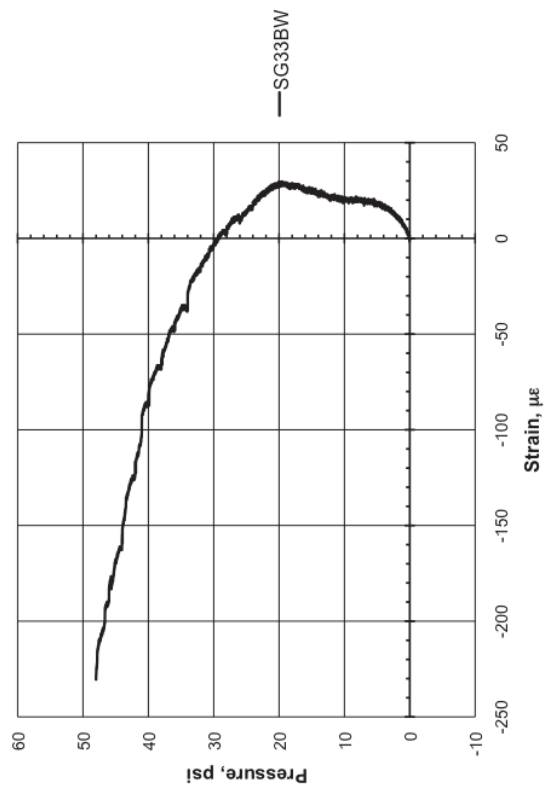
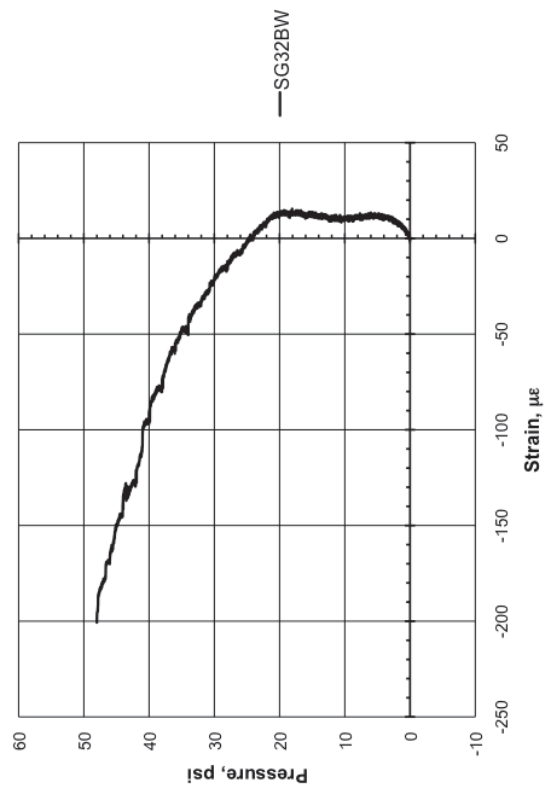
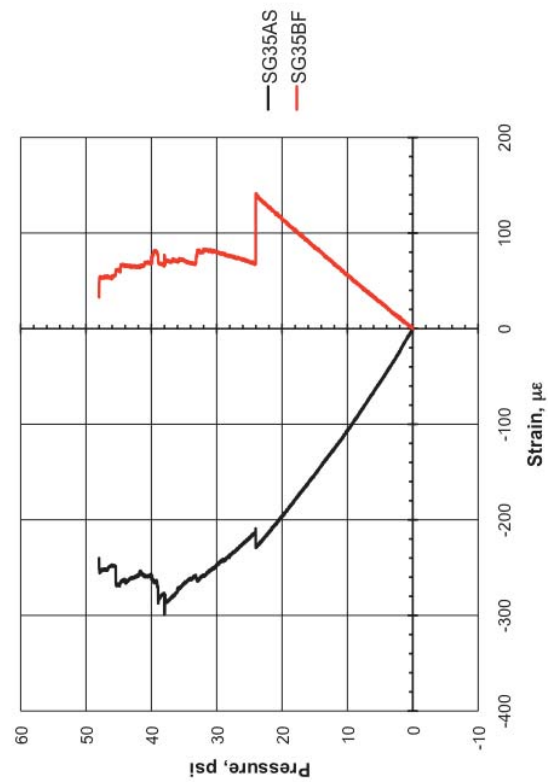
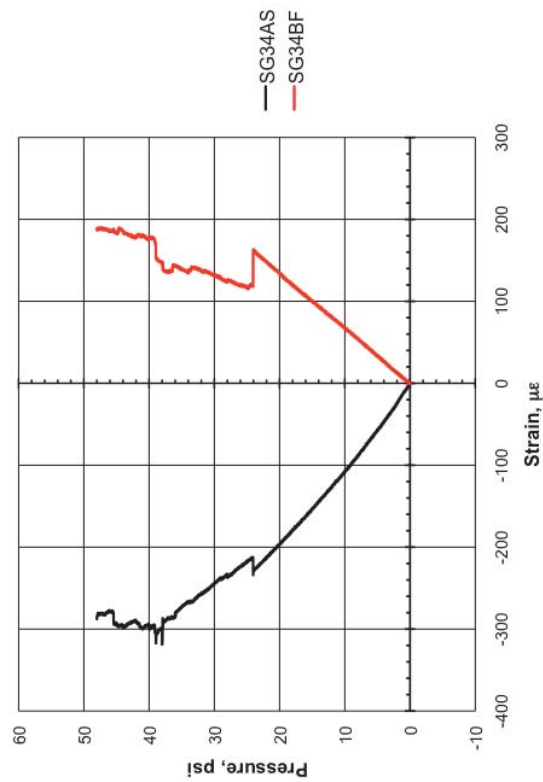
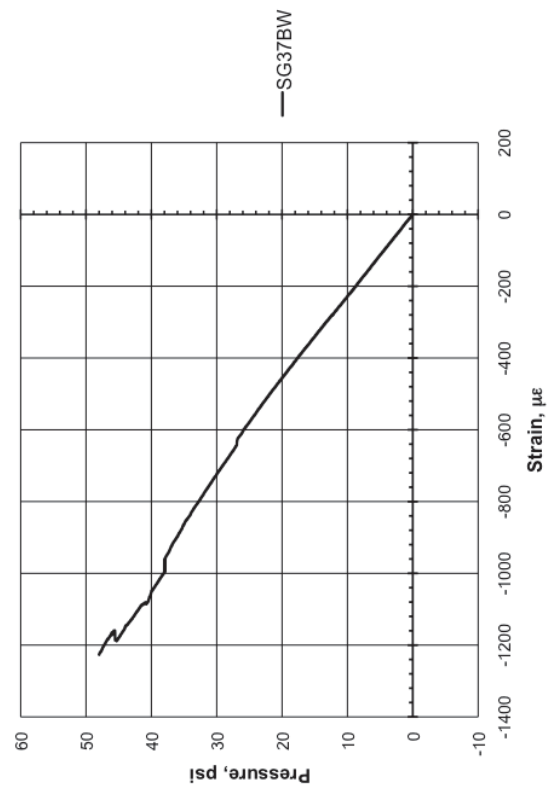
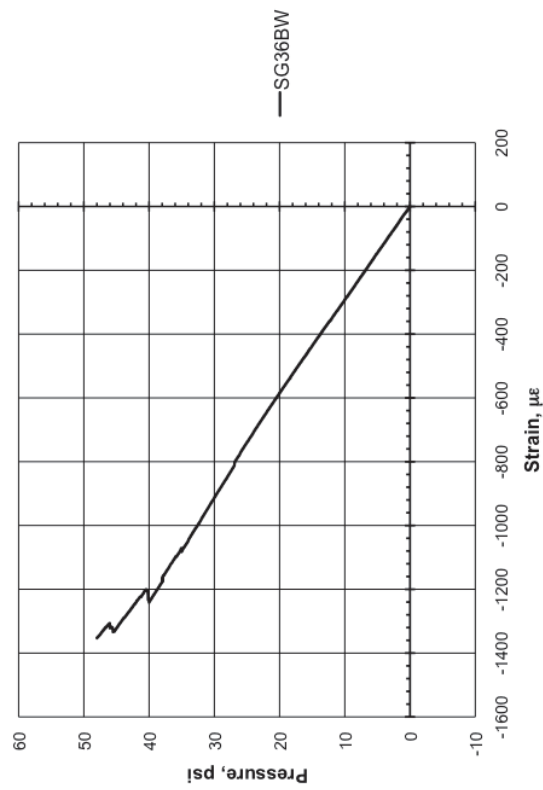


Figure E40. Test to failure, strain gages SG29AS and SG29BF.





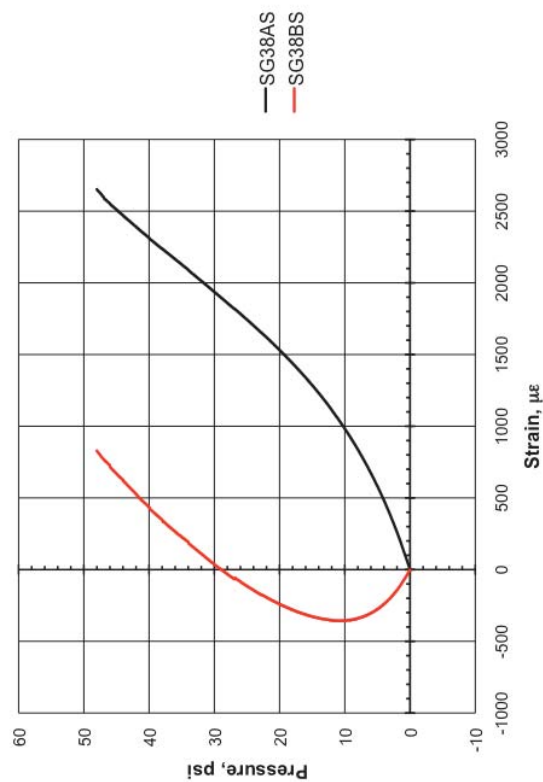


Figure E49. Test to failure, strain gages SG38AS and SG38BS.

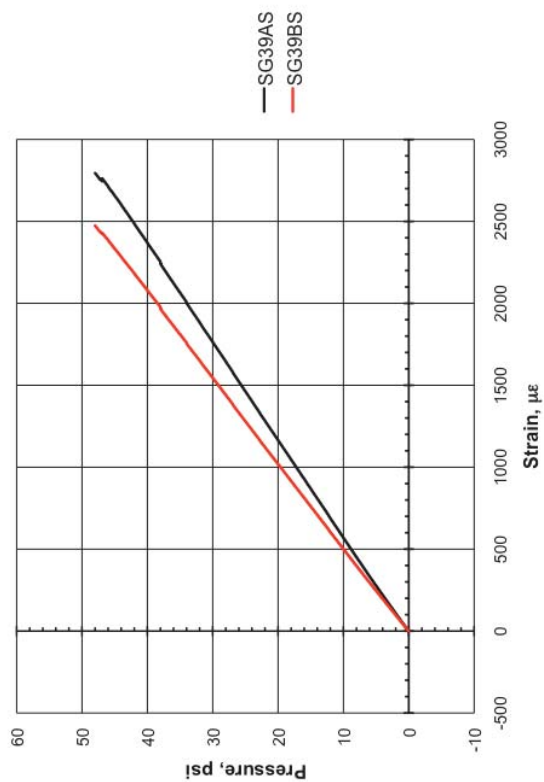


Figure E50. Test to failure, strain gages SG39AS and SG39BS.

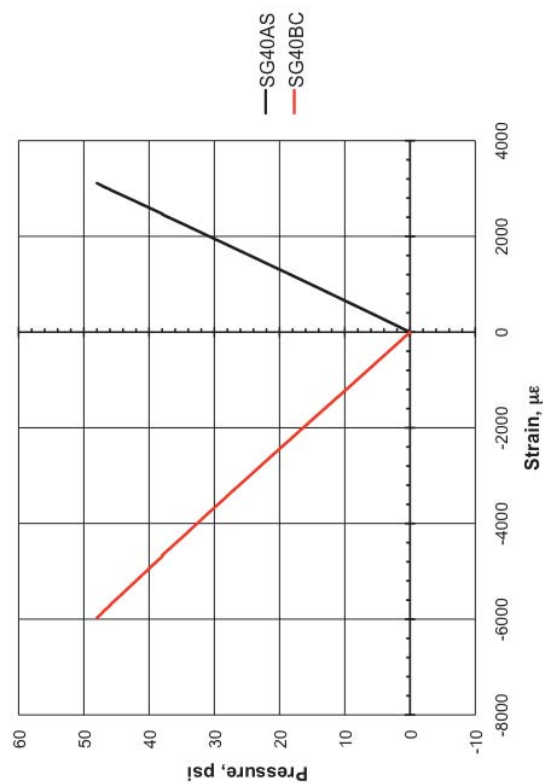


Figure E51. Test to failure, strain gages SG40AS and SG40BC.

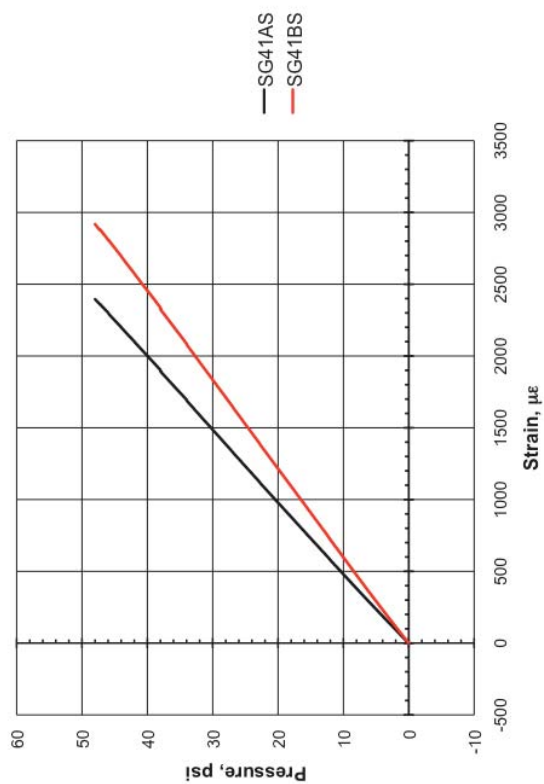


Figure E52. Test to failure, strain gages SG41AS and SG41BS.

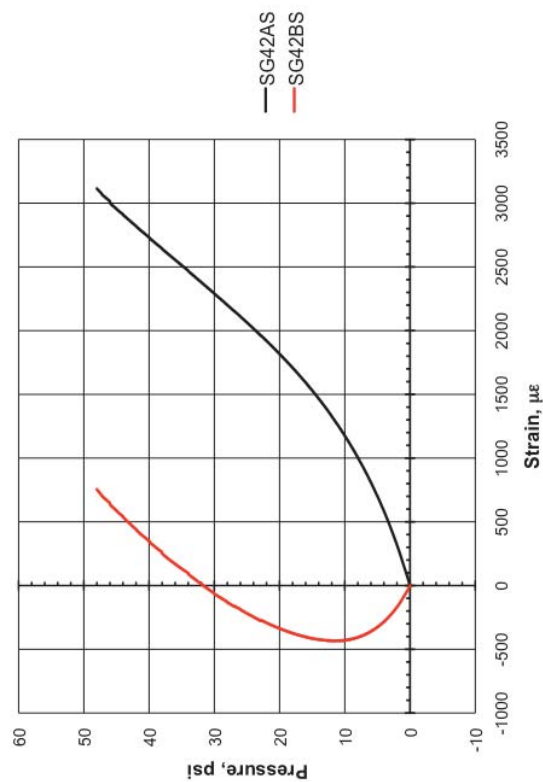


Figure E53. Test to failure, strain gages SG42AS and SG42BS.

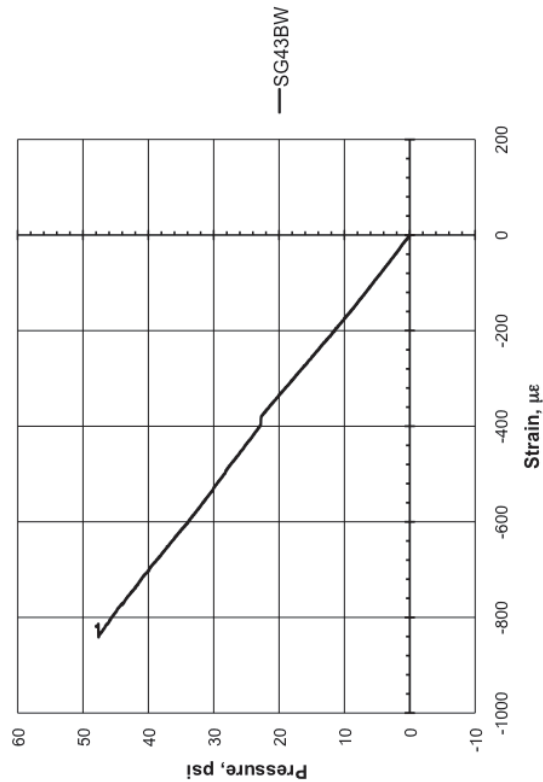


Figure E54. Test to failure, strain gage SG43BW.

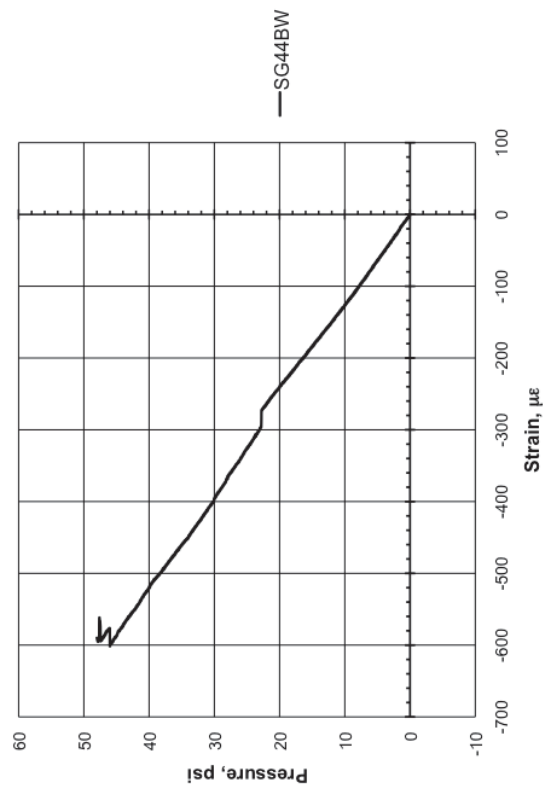


Figure E55. Test to failure, strain gage SG44BW.

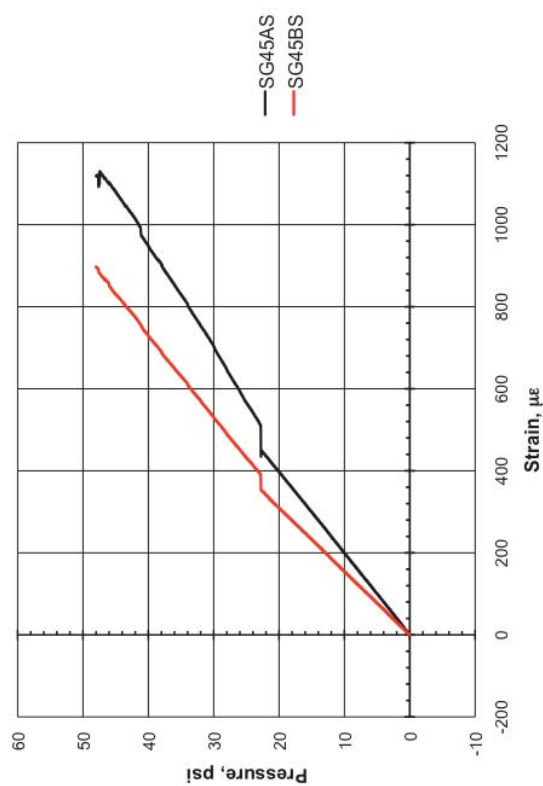


Figure E56. Test to failure, strain gages SG45AS and SG45BS.

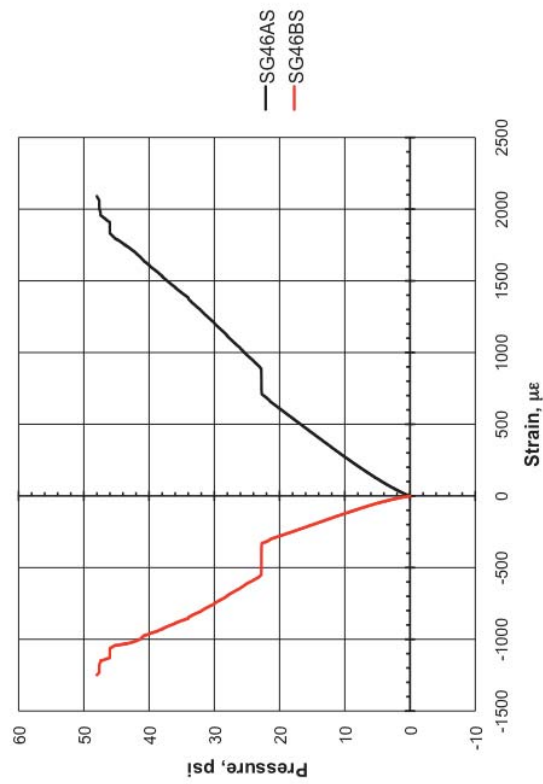


Figure E57. Test to failure, strain gages SG46AS and SG46BS.

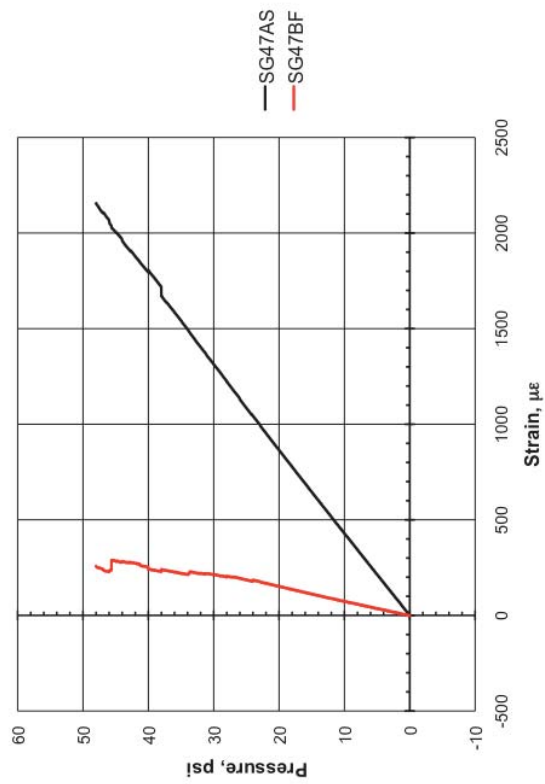


Figure E58. Test to failure, strain gages SG47AS and SG47BF.

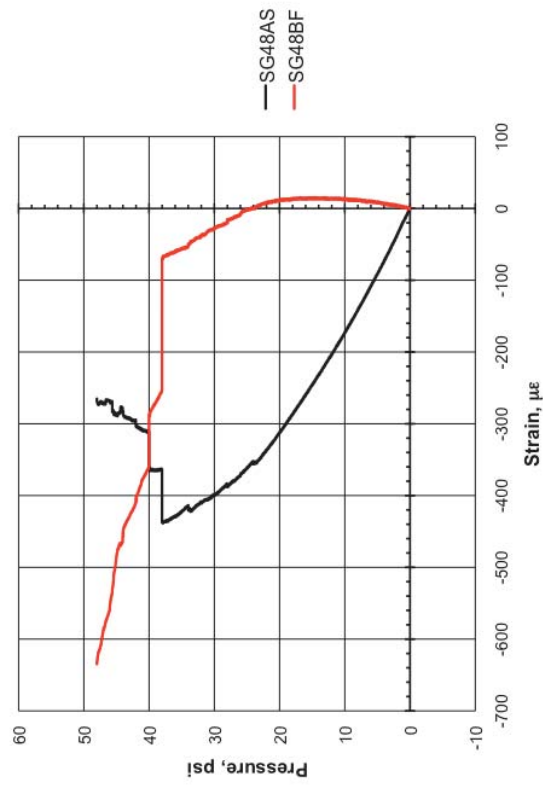


Figure E59. Test to failure, strain gages SG48AS and SG48BF.

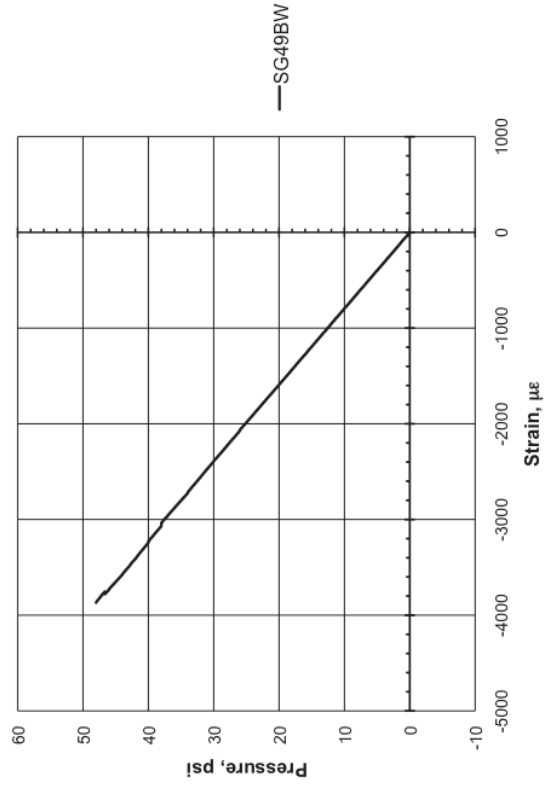


Figure E60. Test to failure, strain gage SG49BW.

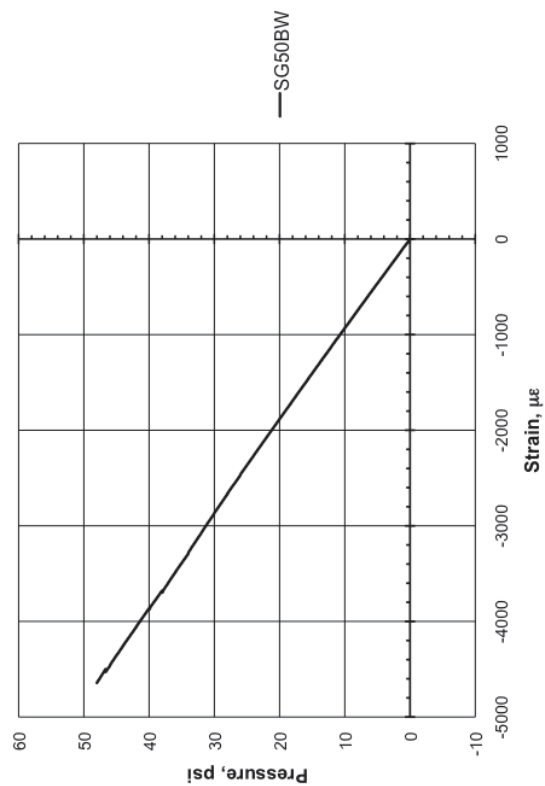


Figure E61. Test to failure, strain gage SG50BW.

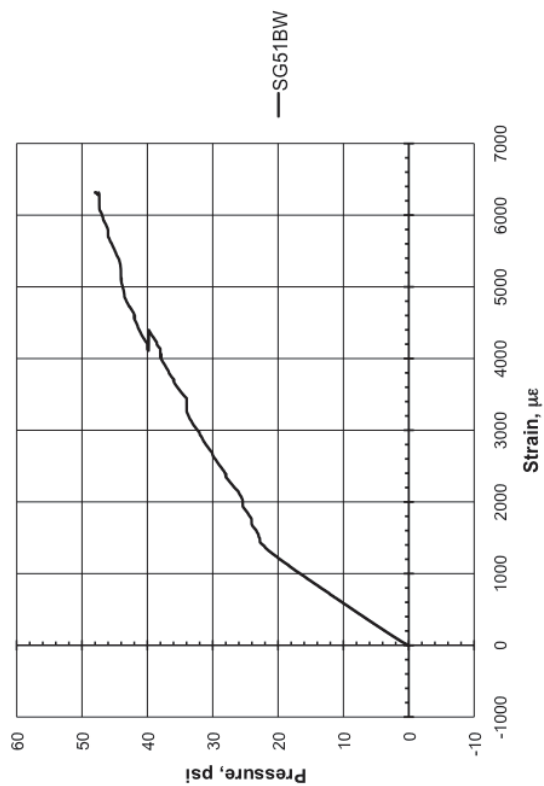


Figure E62. Test to failure, strain gage SG51BW.

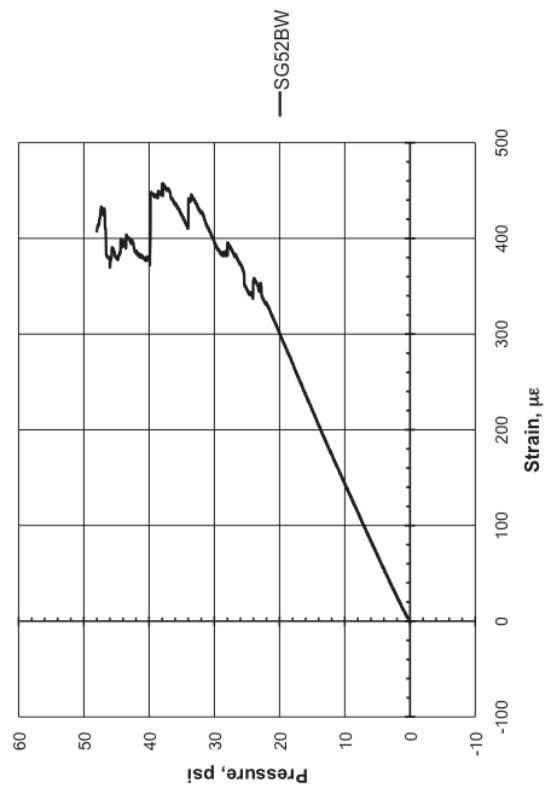


Figure E63. Test to failure, strain gage SG52BW.

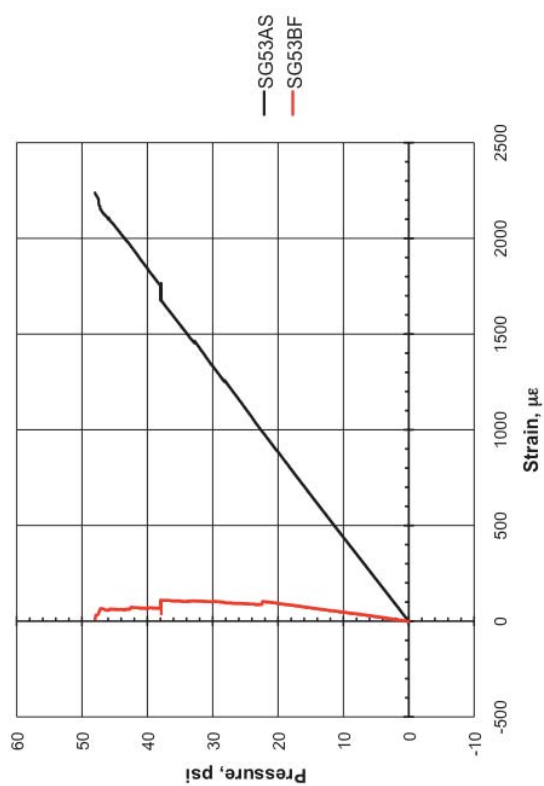


Figure E64. Test to failure, strain gages SG53AS and SG53BF.

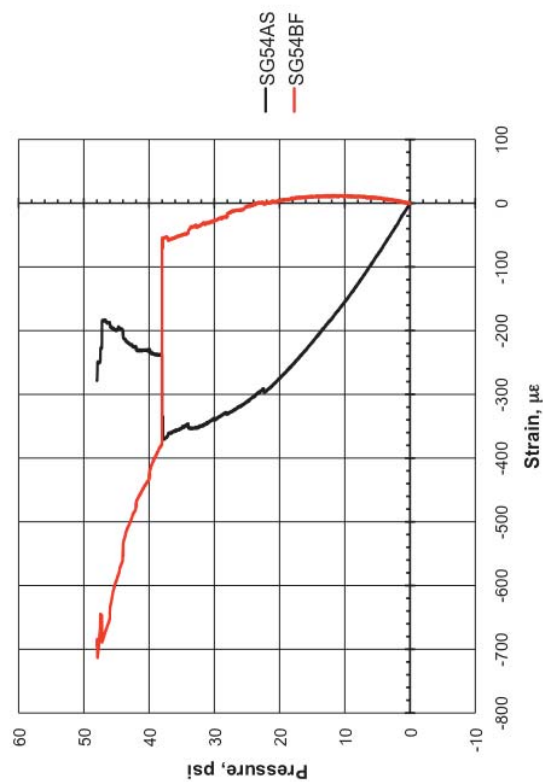


Figure E65. Test to failure, strain gages SG54AS and SG54BF.

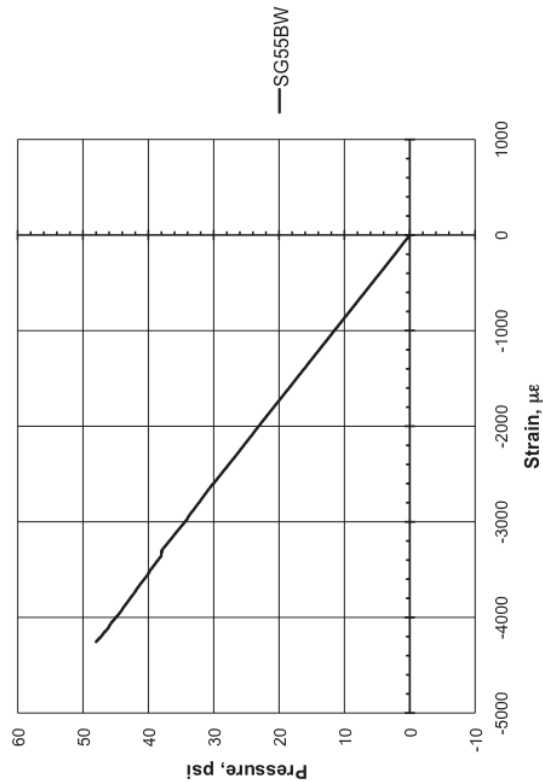


Figure E66. Test to failure, strain gage SG55BW.

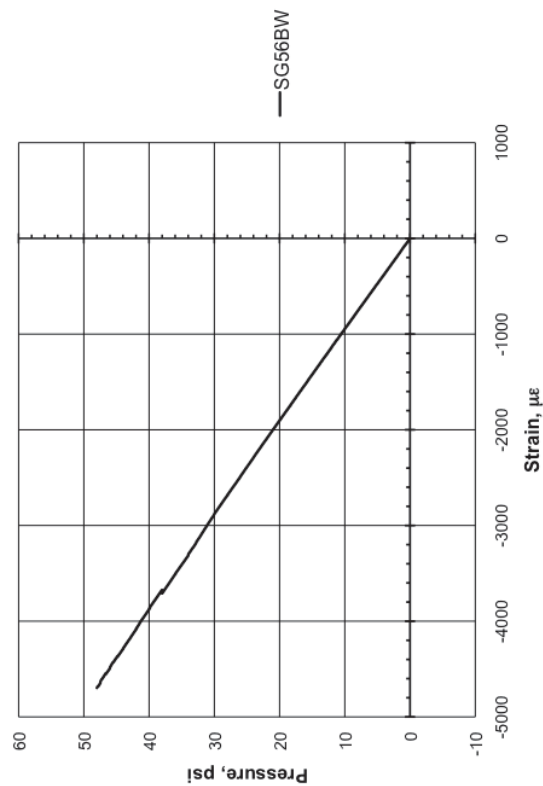


Figure E67. Test to failure, strain gage SG56BW.

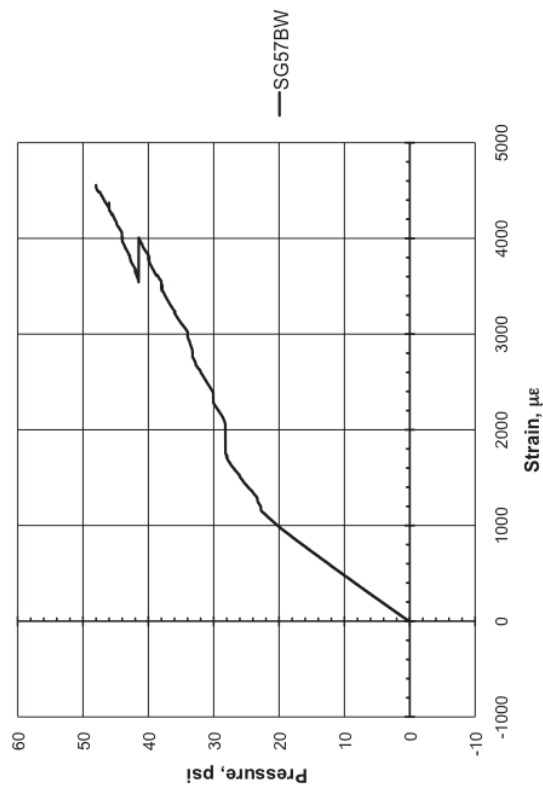


Figure E68. Test to failure, strain gage SG57BW.



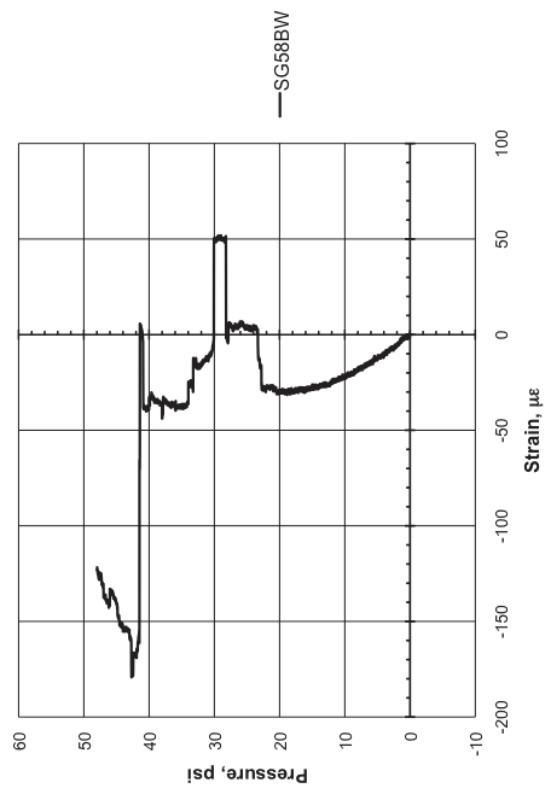


Figure E69. Test to failure, strain gage SG58BW.

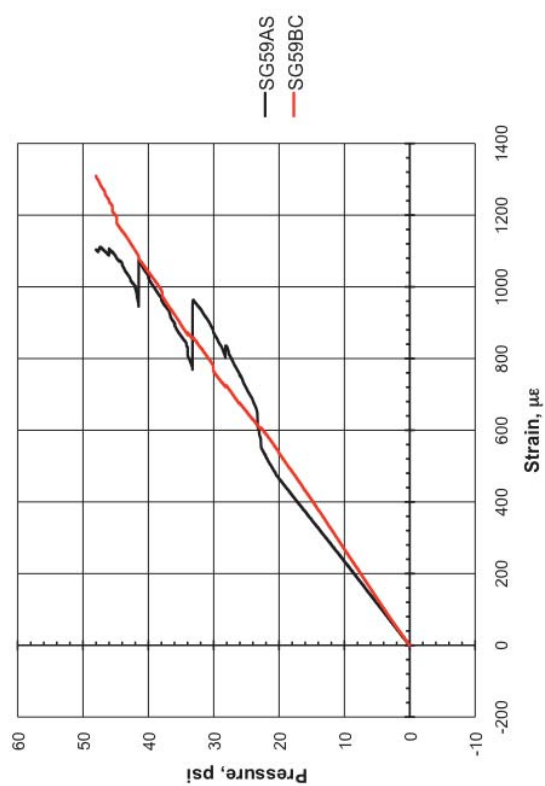


Figure E70. Test to failure, strain gages SG59AS and SG59BC.

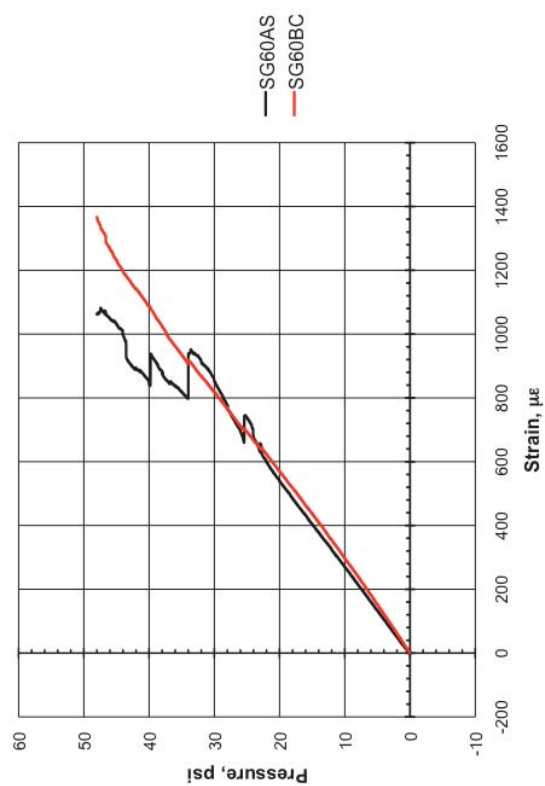


Figure E71. Test to failure, strain gages SG60AS and SG60BC.

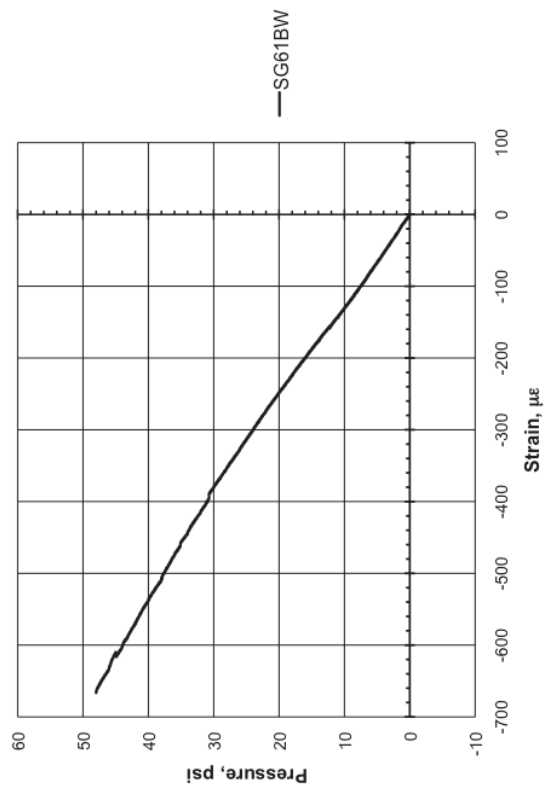


Figure E72. Test to failure, strain gage SG61BW.

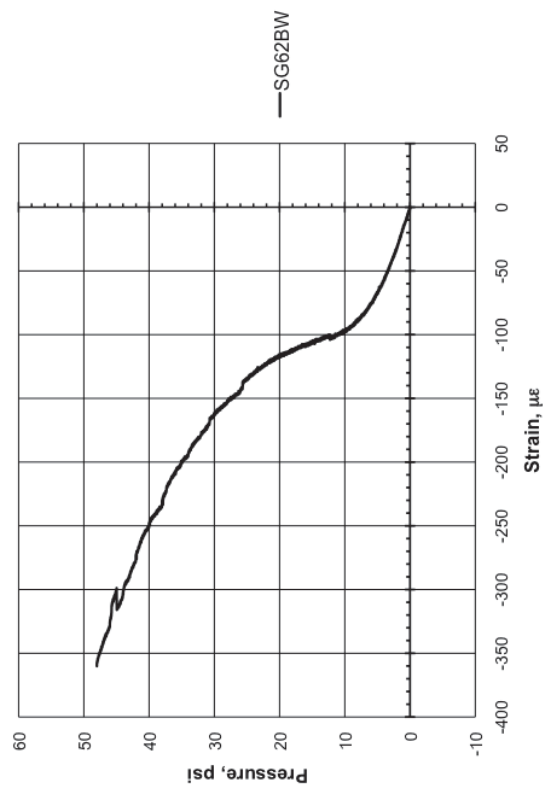


Figure E73. Test to failure, strain gage SG62BW.

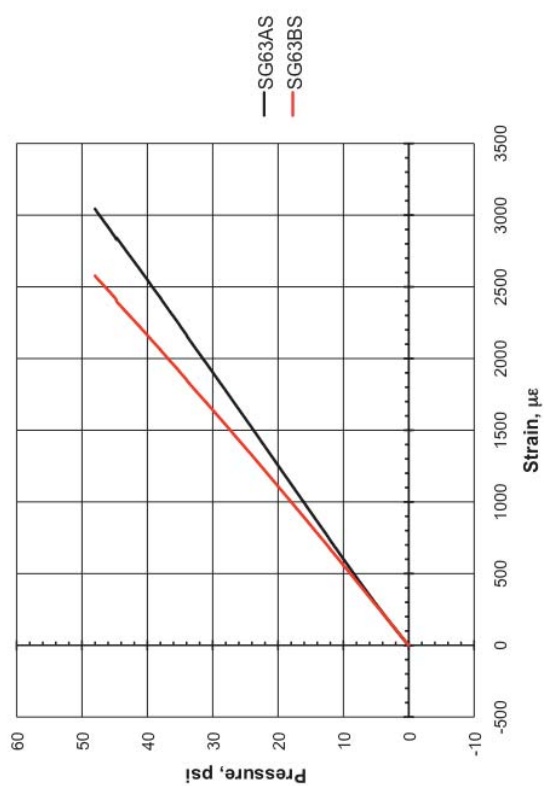


Figure E74. Test to failure, strain gages SG63AS and SG63BS.

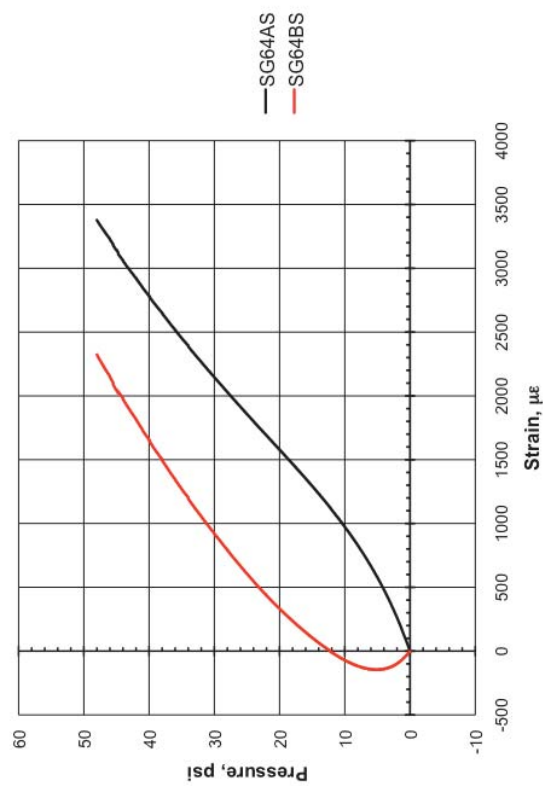


Figure E75. Test to failure, strain gages SG64AS and SG64BS.

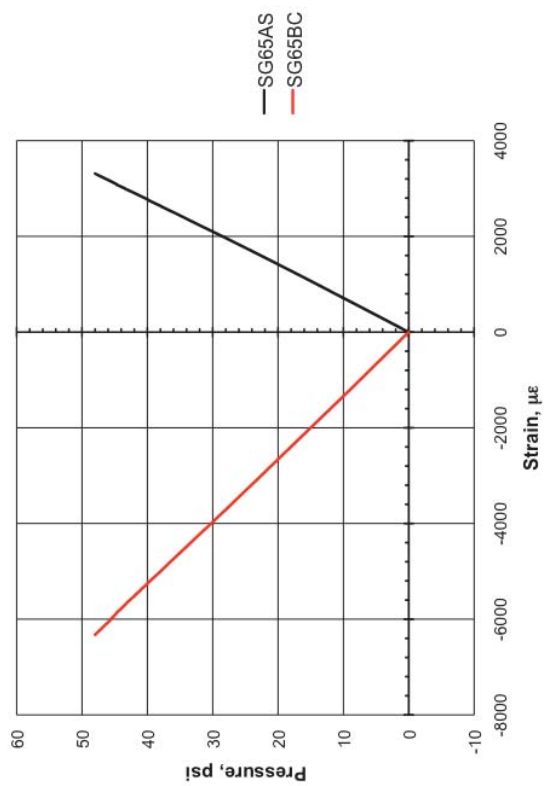


Figure E76. Test to failure, strain gages SG65AS and SG65BC.

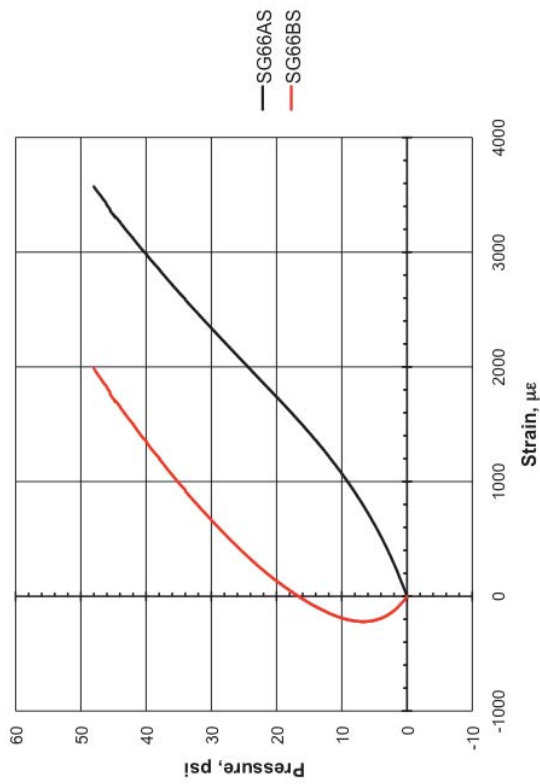


Figure E77. Test to failure, strain gages SG66AS and SG66BS.

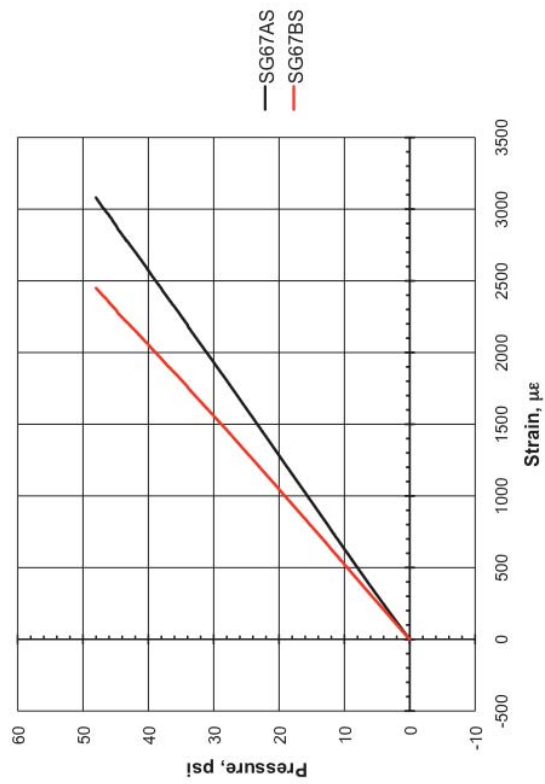


Figure E78. Test to failure, strain gages SG67AS and SG67BS.

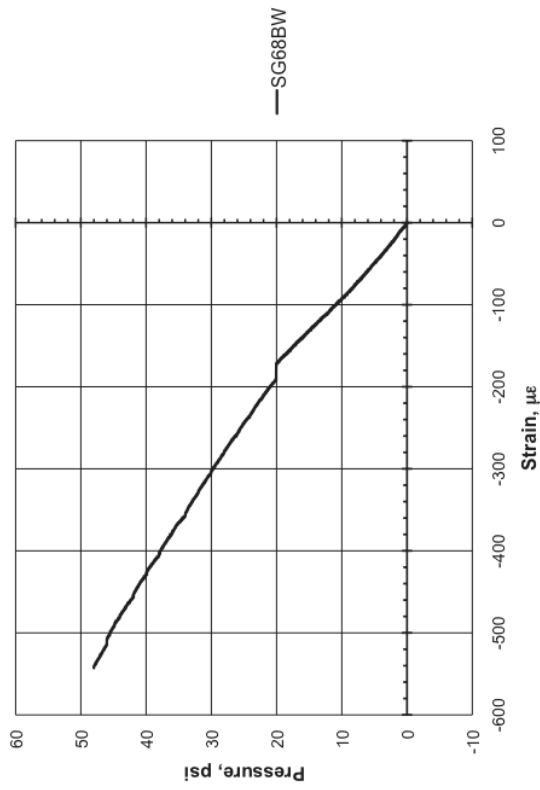


Figure E79. Test to failure, strain gage SG68BW.

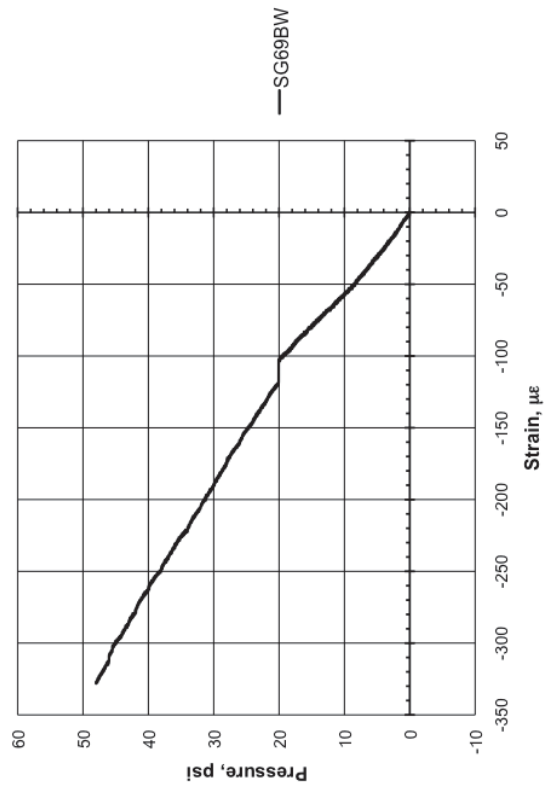


Figure E80. Test to failure, strain gage SG69BW.

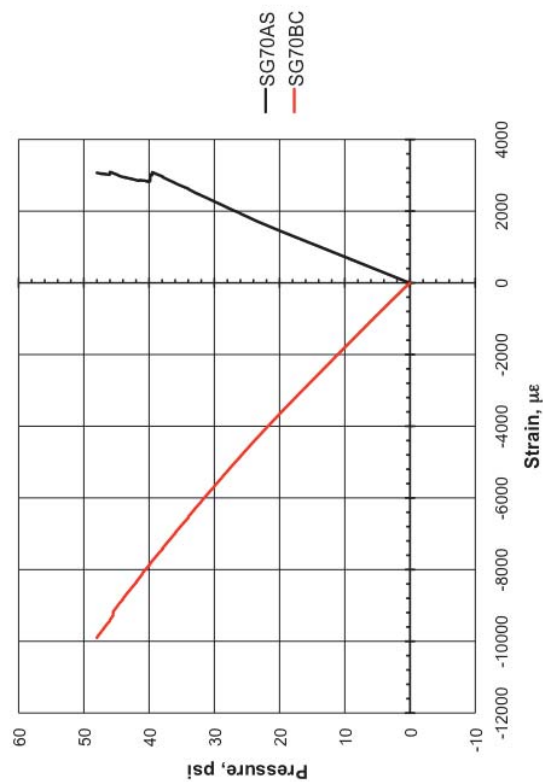


Figure E81. Test to failure, strain gages SG70AS and SG70BC.

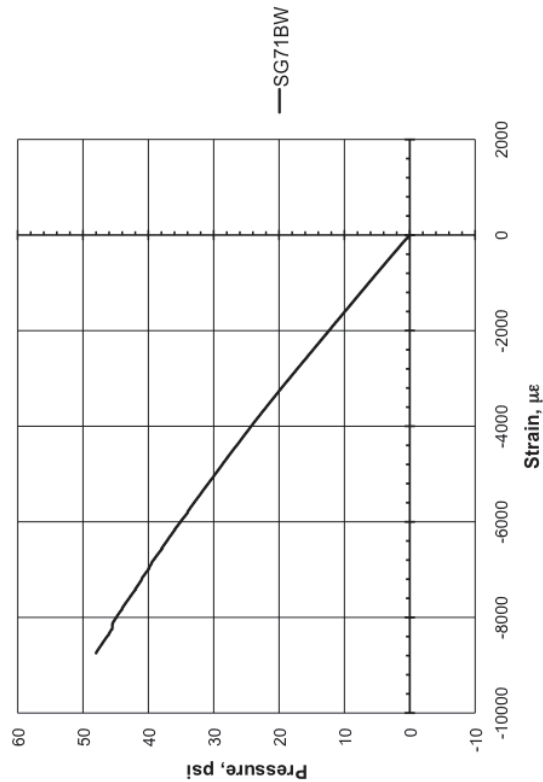


Figure E82. Test to failure, strain gage SG71BW.

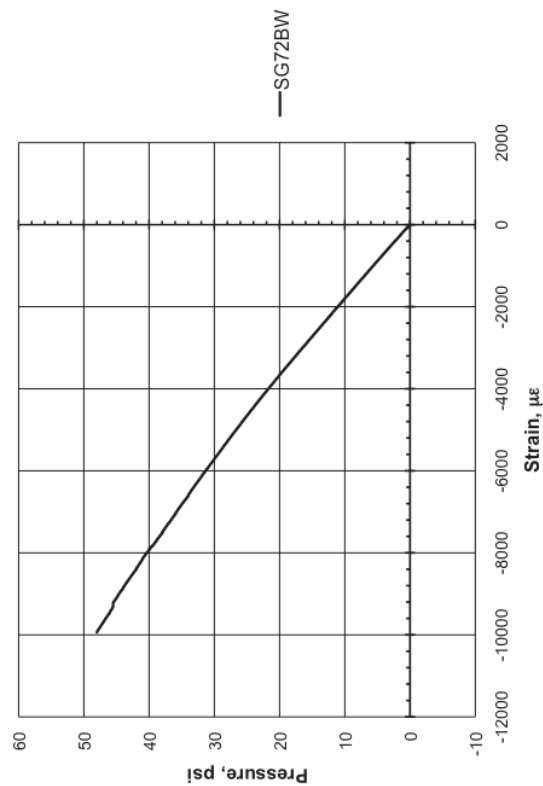


Figure E83. Test to failure, strain gage SG72BW.

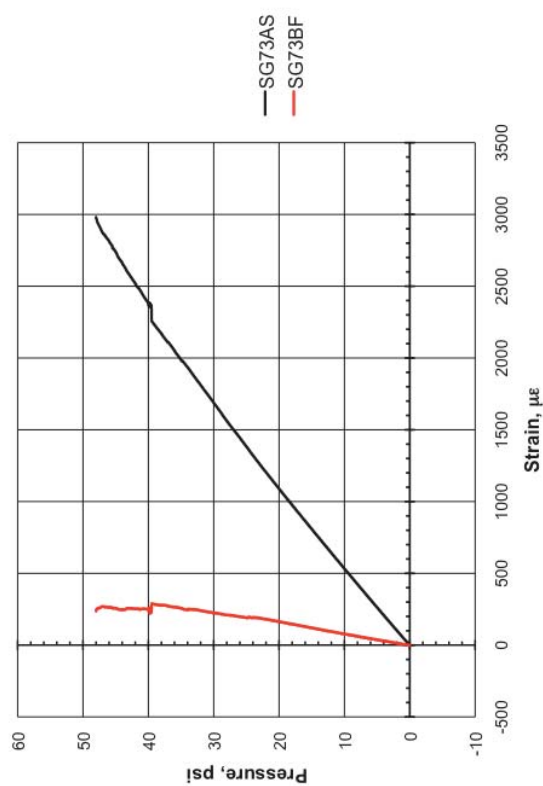


Figure E84. Test to failure, strain gages SG73AS and SG73BF.

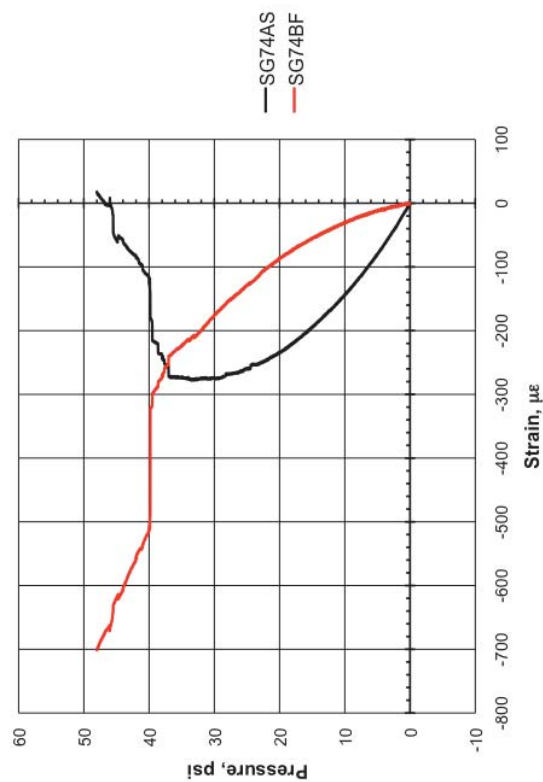


Figure E85. Test to failure, strain gages SG74AS and SG74BF.

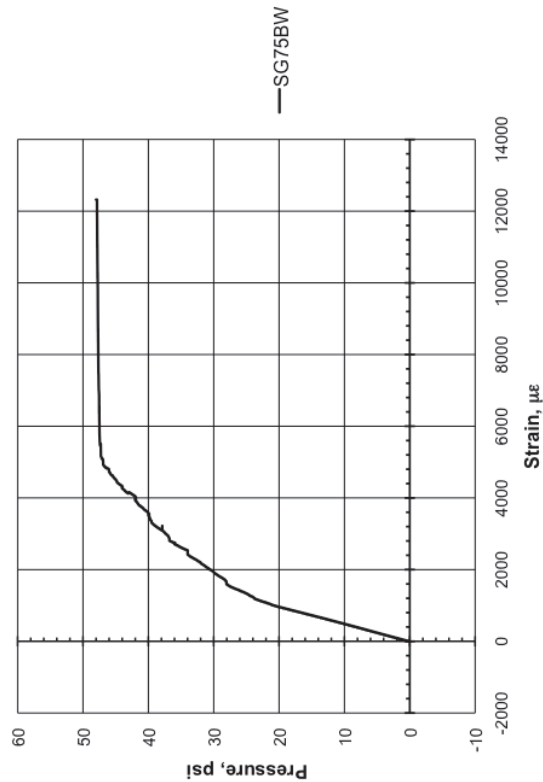


Figure E86. Test to failure, strain gage SG75BW.

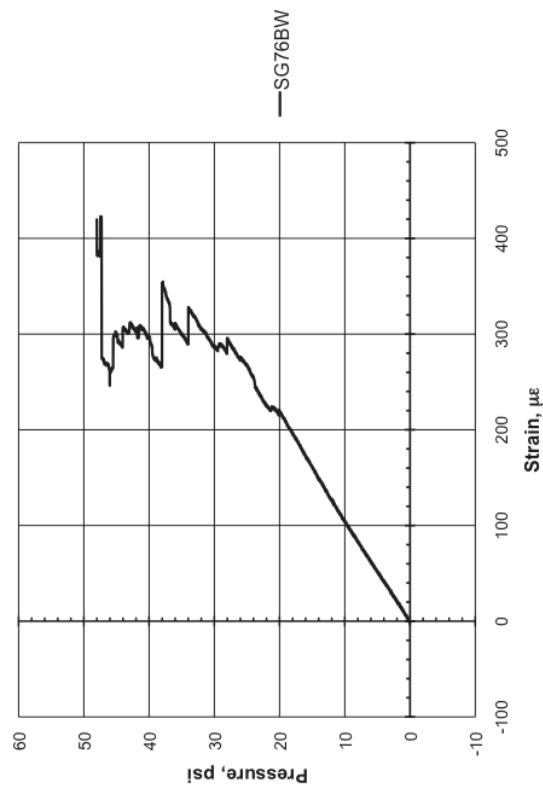


Figure E87. Test to failure, strain gage SG76BW.

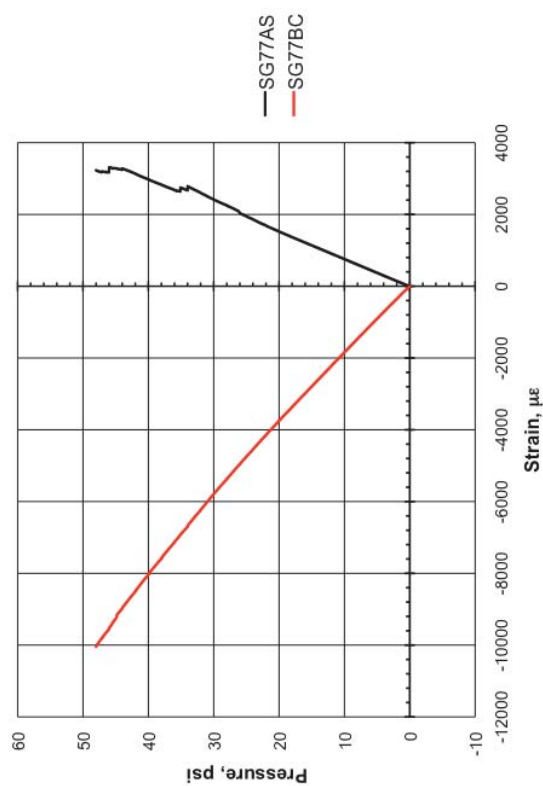


Figure E88. Test to failure, strain gages SG77AS and SG77BC.

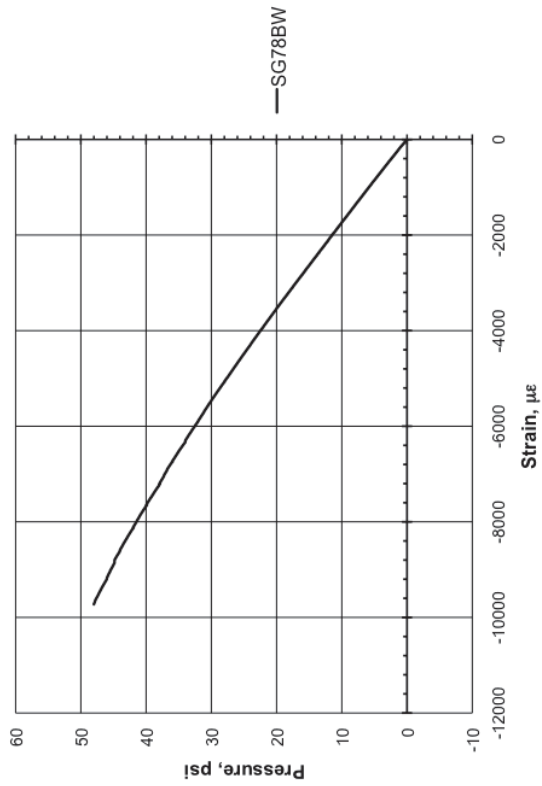


Figure E89. Test to failure, strain gage SG78BW.

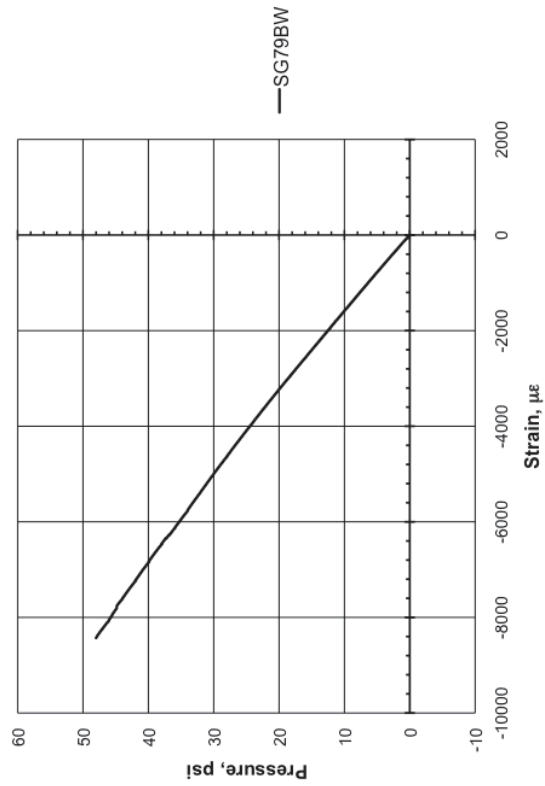


Figure E90. Test to failure, strain gage SG79BW.

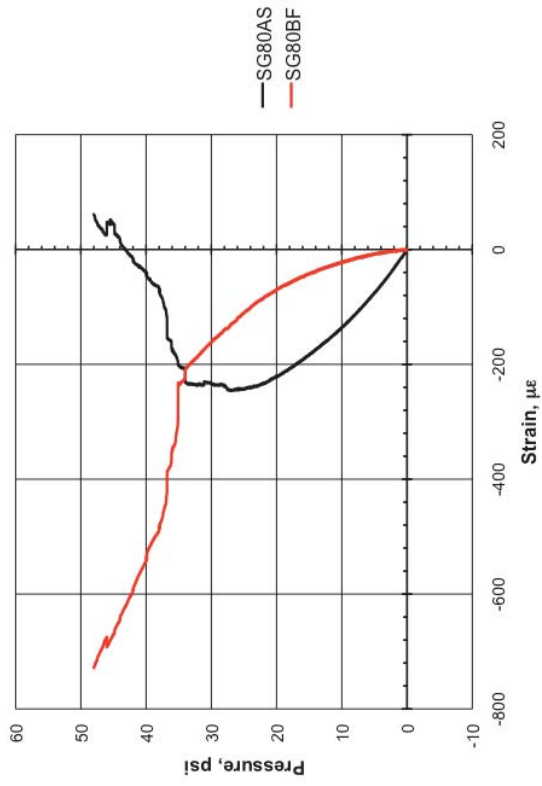


Figure E91. Test to failure, strain gages SG80AS and SG80BF.

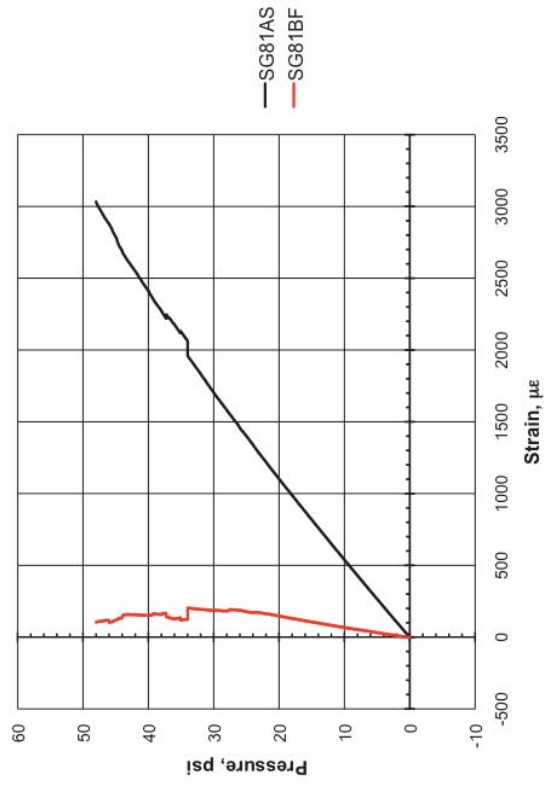


Figure E92. Test to failure, strain gages SG81AS and SG81BF.

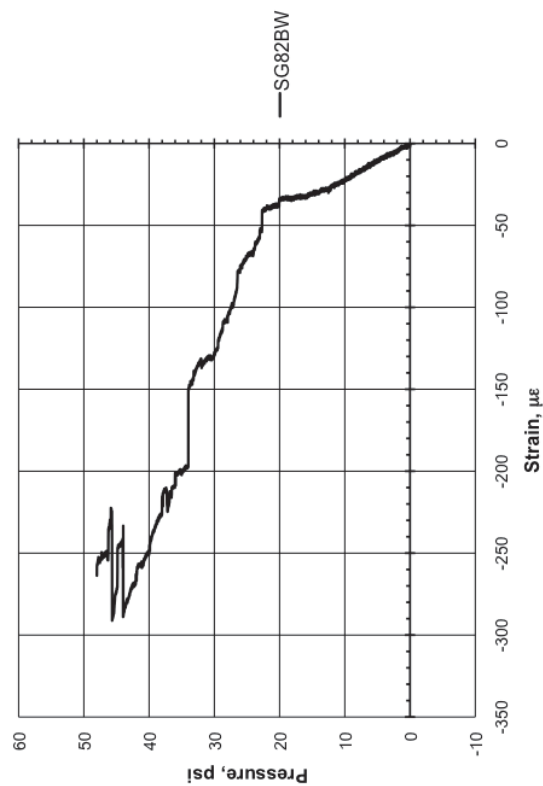


Figure E93. Test to failure, strain gage SG82BW.

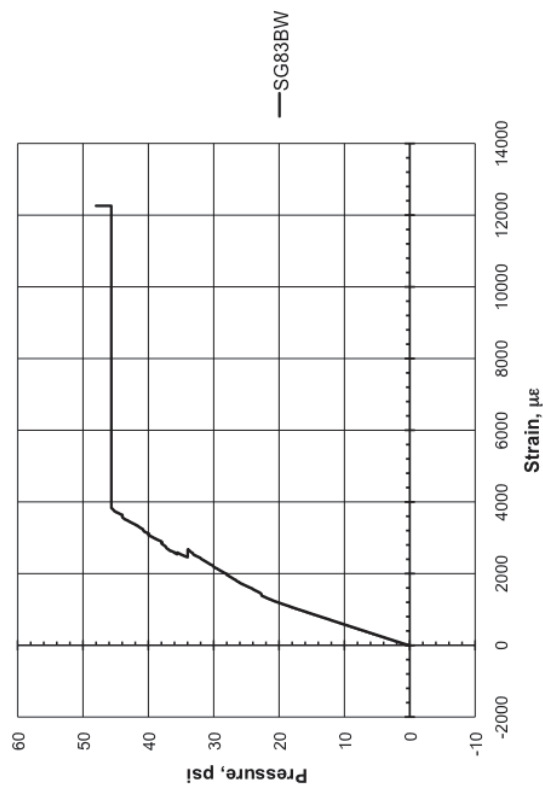


Figure E94. Test to failure, strain gage SG83BW.

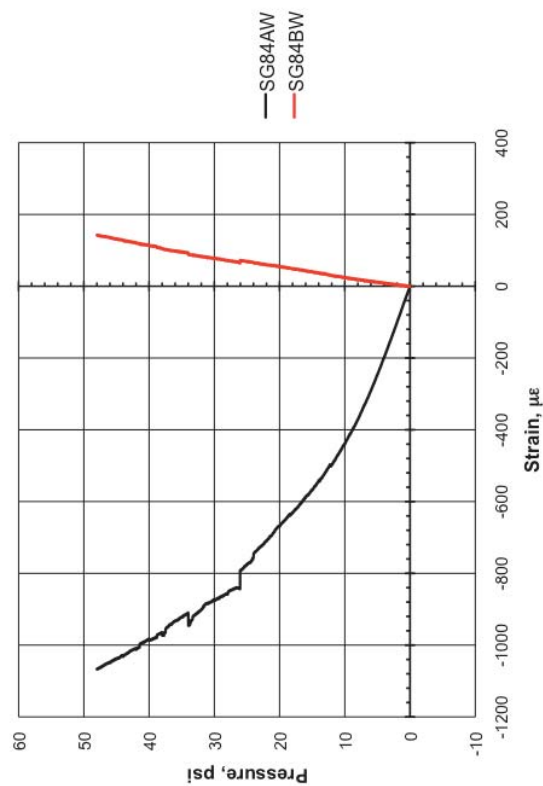


Figure E95. Test to failure, strain gages SG84AW and SG84BW.

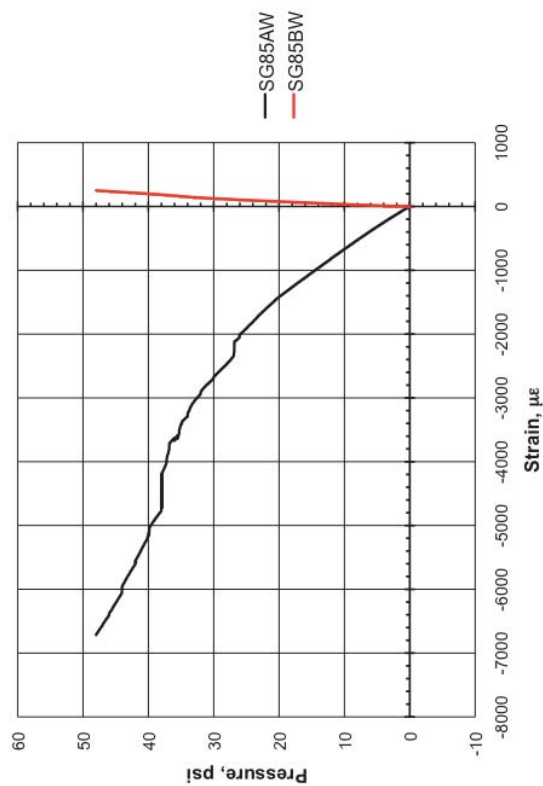


Figure E96. Test to failure, strain gages SG85AW and SG85BW.

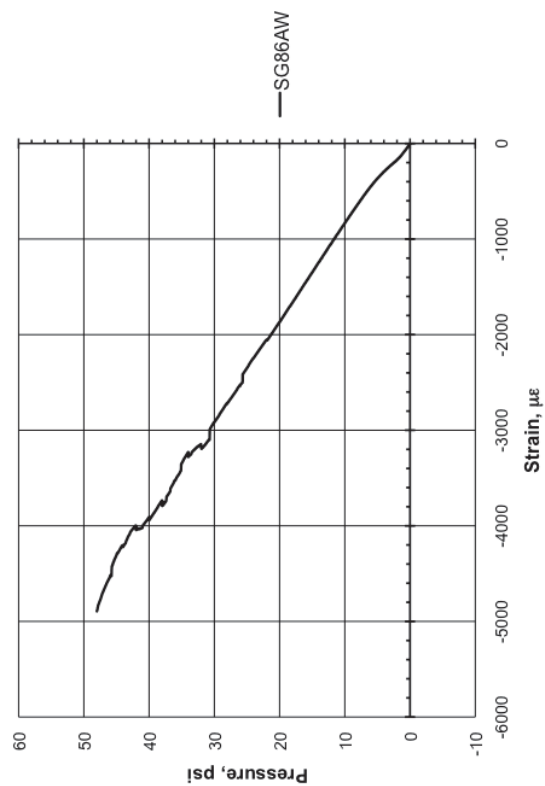


Figure E97. Test to failure, strain gage SG86AW.

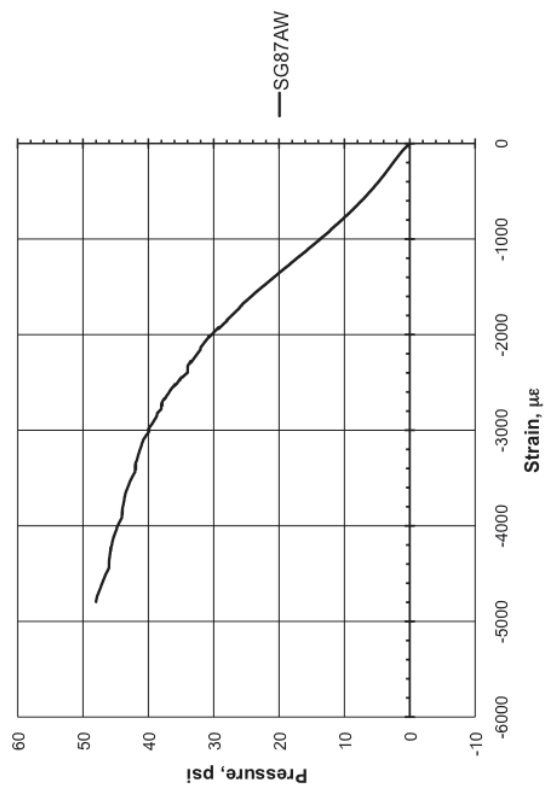


Figure E98. Test to failure, strain gage SG87AW.

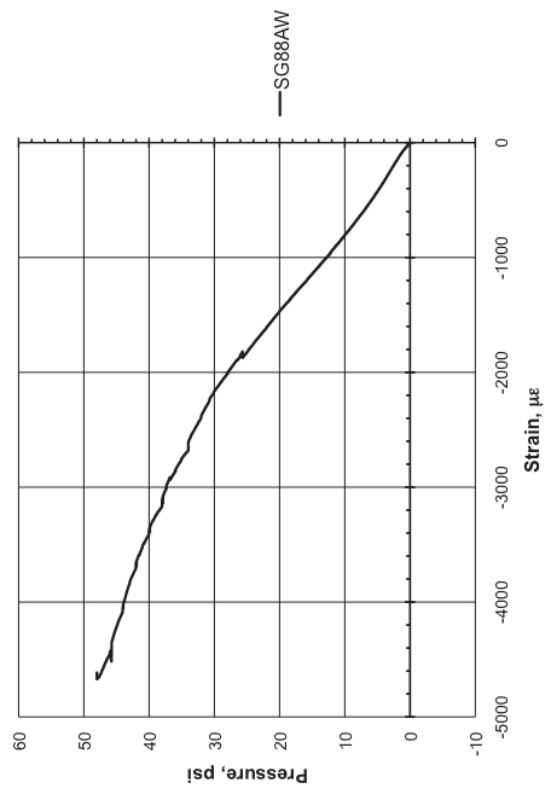


Figure E99. Test to failure, strain gage SG88AW.

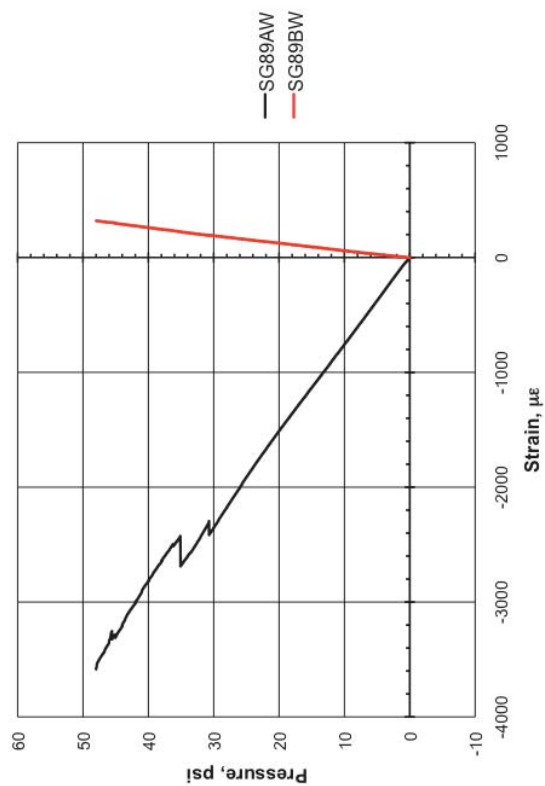


Figure E100. Test to failure, strain gages SG89AW and SG89BW.



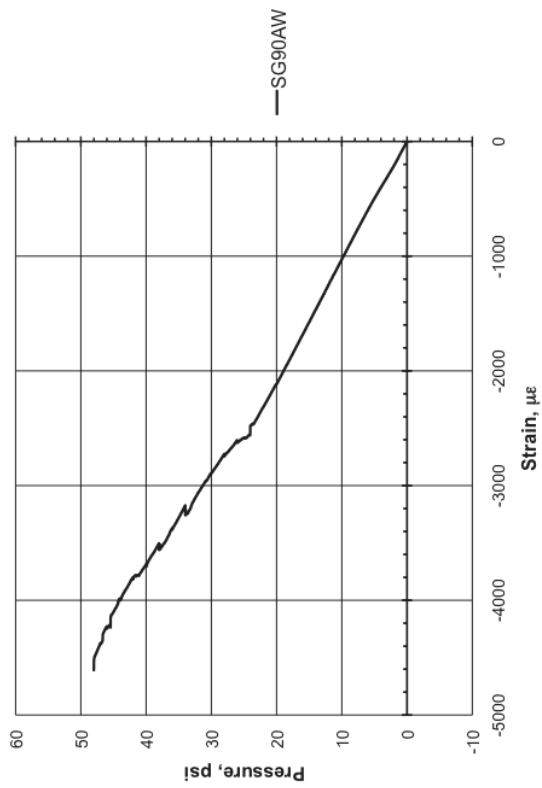


Figure E101. Test to failure, strain gage SG90AW.

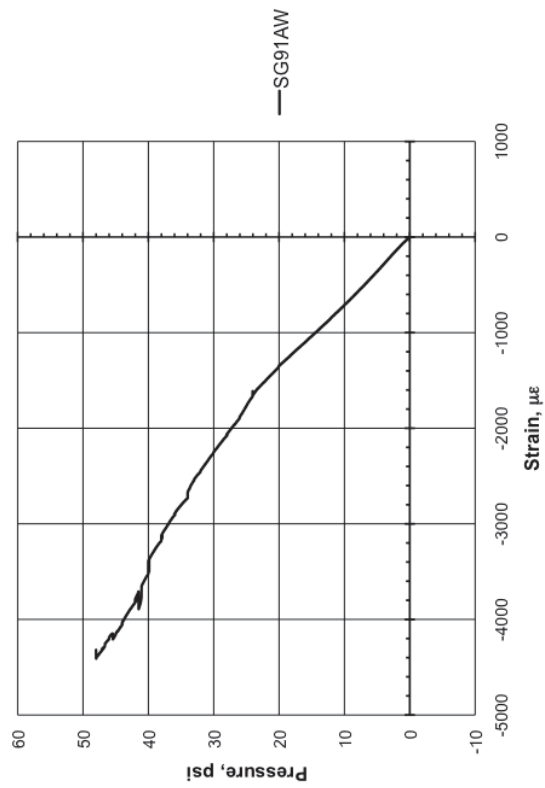


Figure E102. Test to failure, strain gage SG91AW.

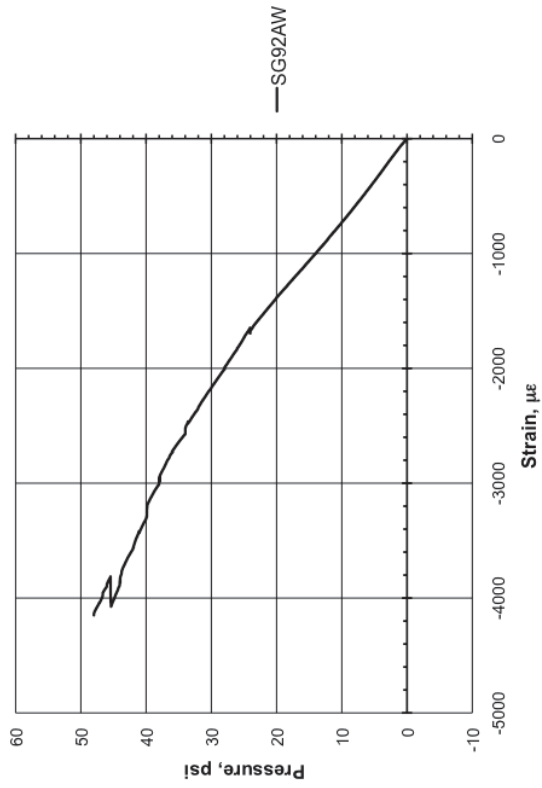


Figure E103. Test to failure, strain gage SG92AW.

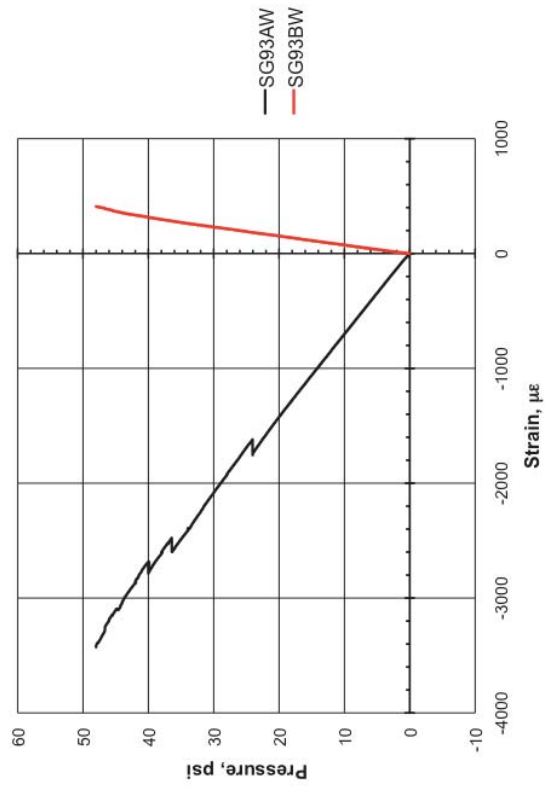


Figure E104. Test to failure, strain gages SG93AW and SG93BW.

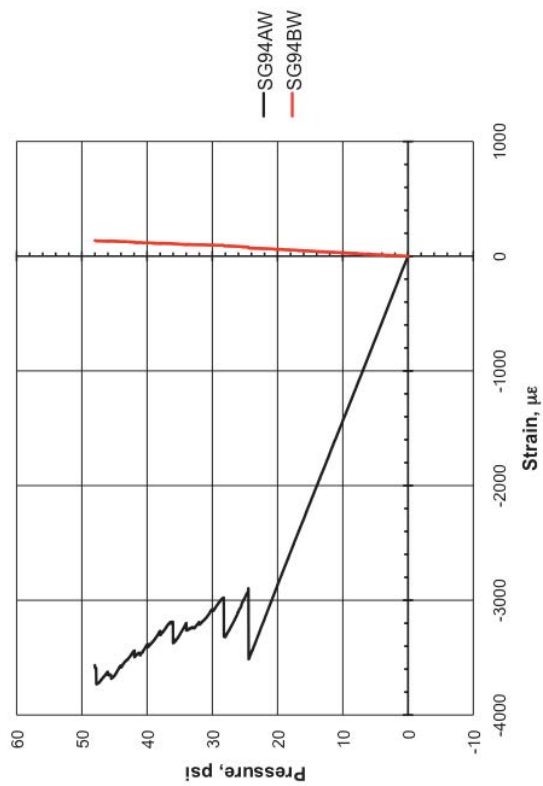


Figure E105. Test to failure, strain gages SG94AW and SG94BW.

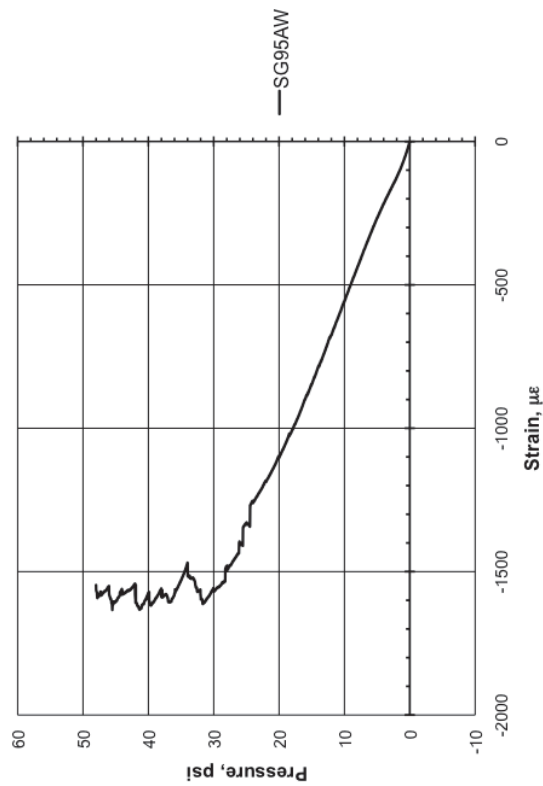


Figure E106. Test to failure, strain gage SG95AW.

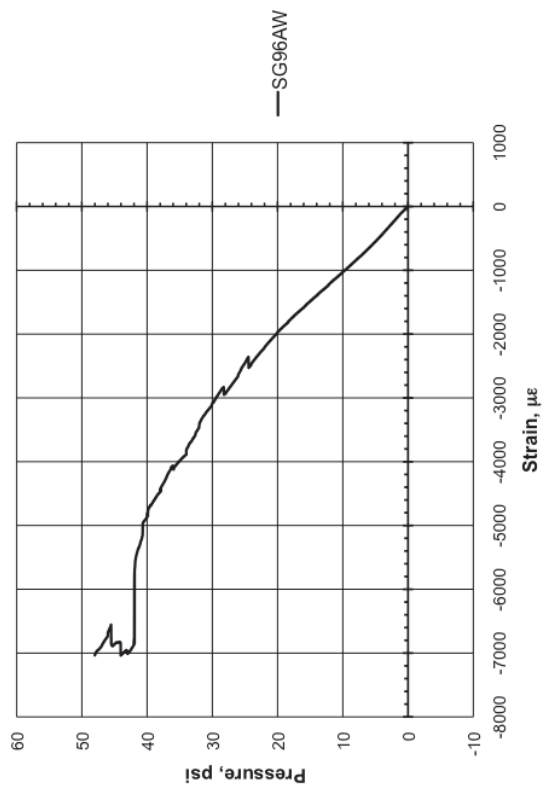


Figure E107. Test to failure, strain gage SG96AW.

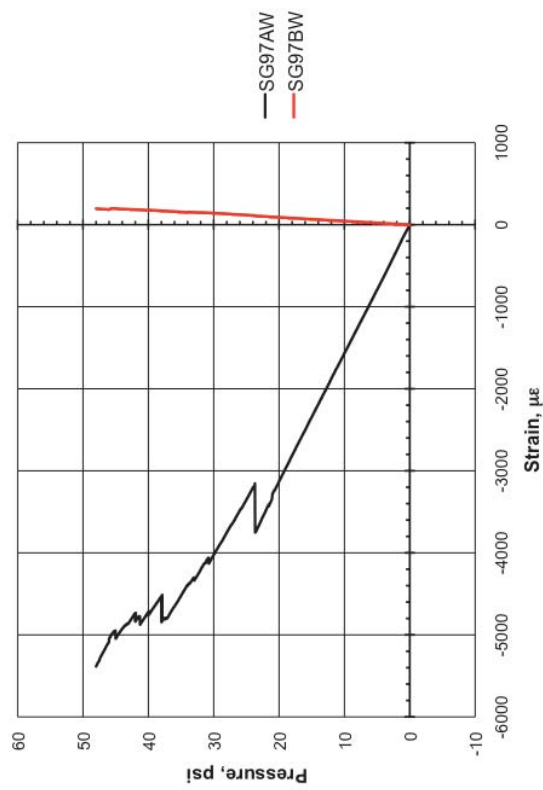
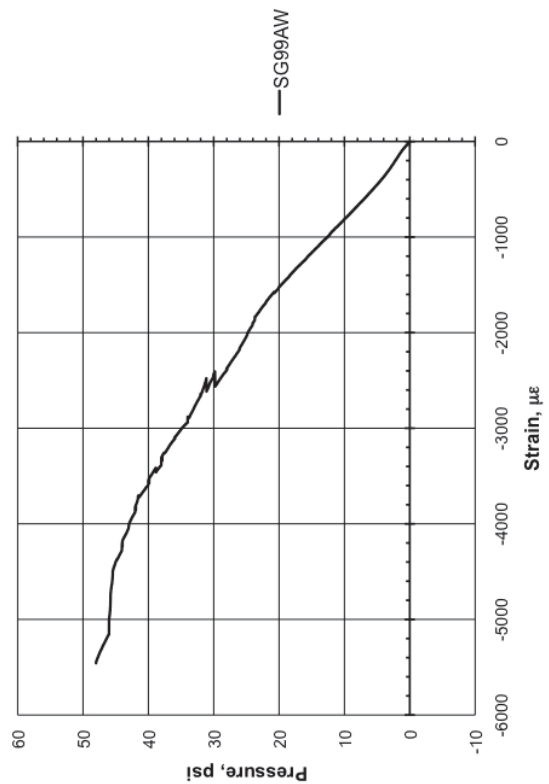
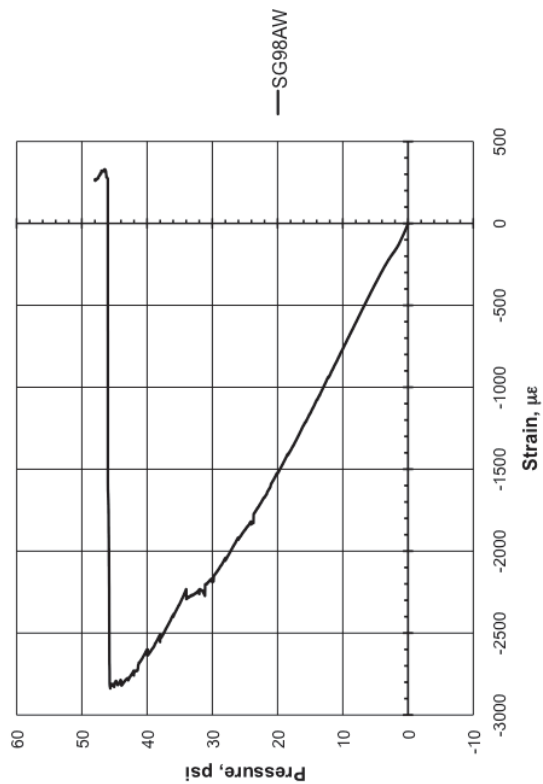
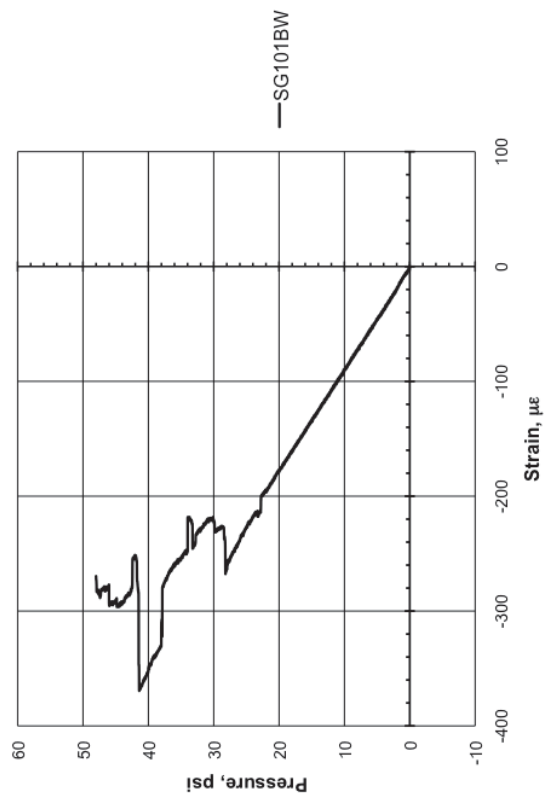
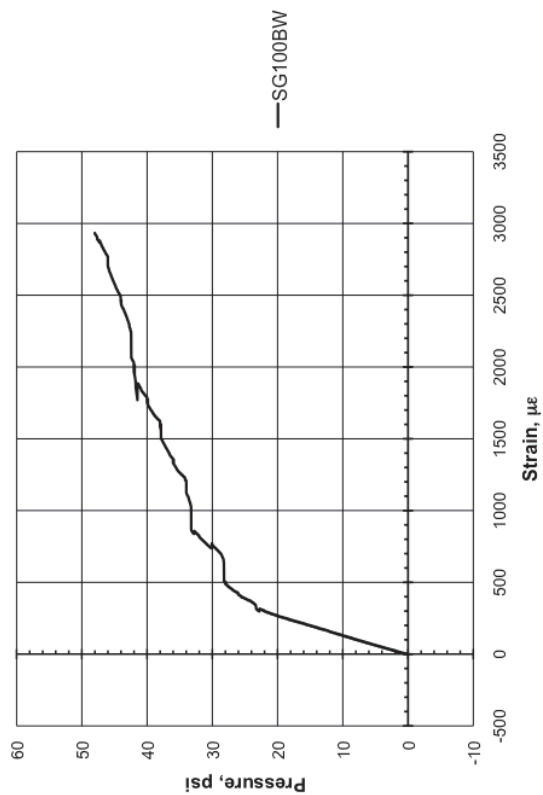
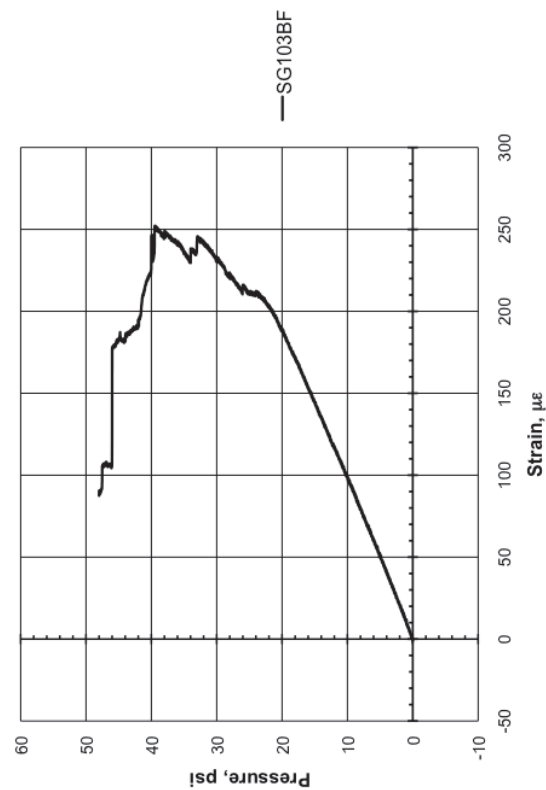
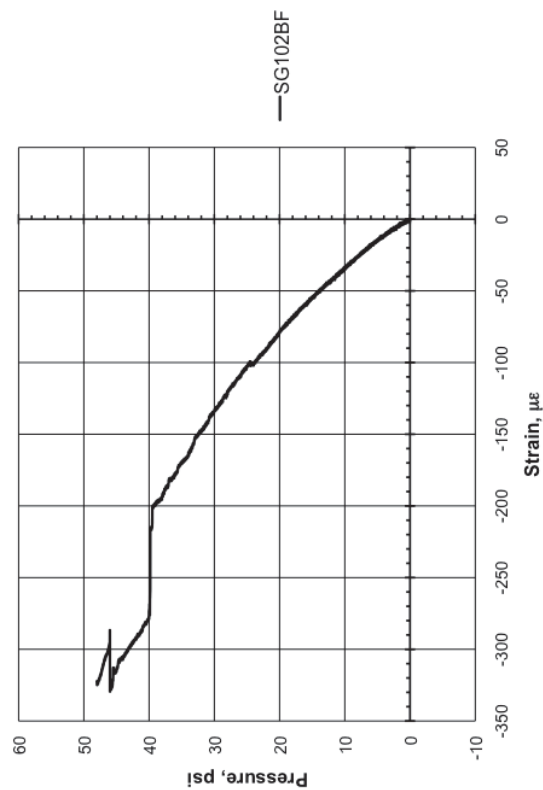
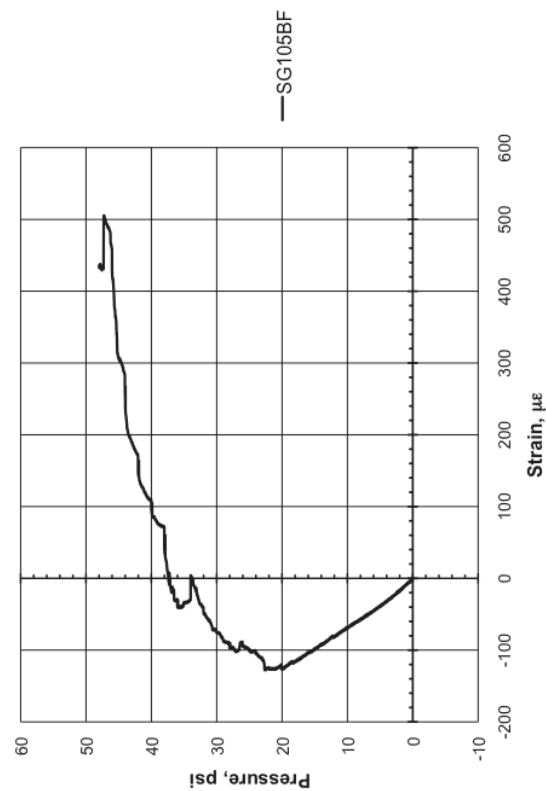
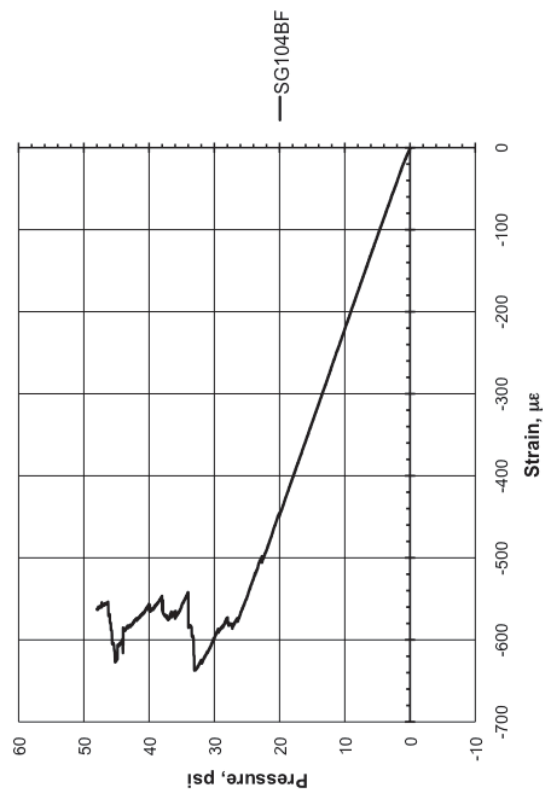


Figure E108. Test to failure, strain gages SG97AW and SG97BW.





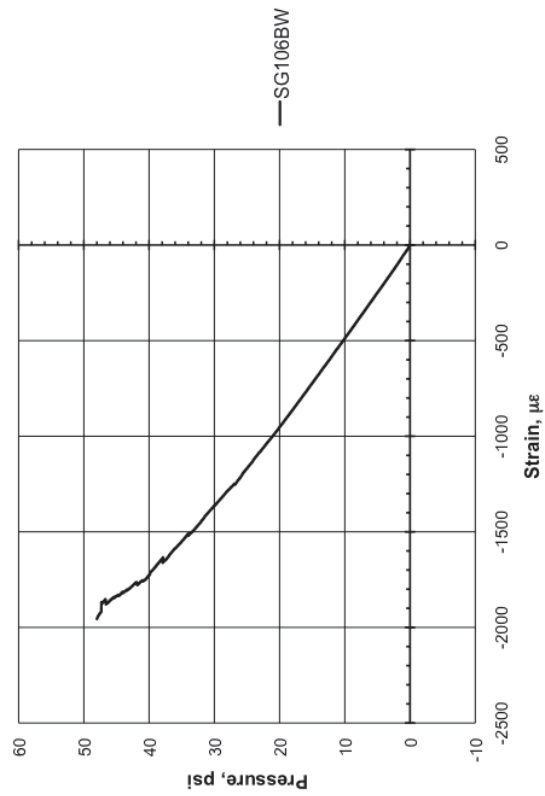


Figure E117. Test to failure, strain gage SG106BW.

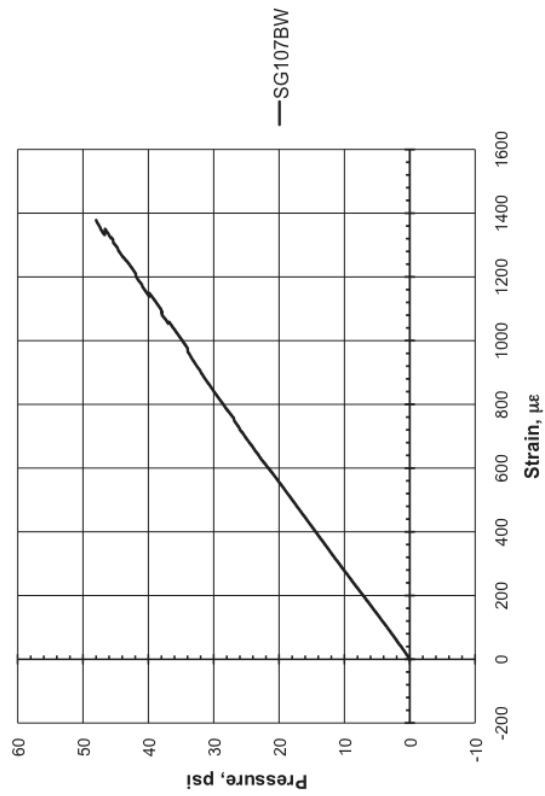


Figure E118. Test to failure, strain gage SG107BW.

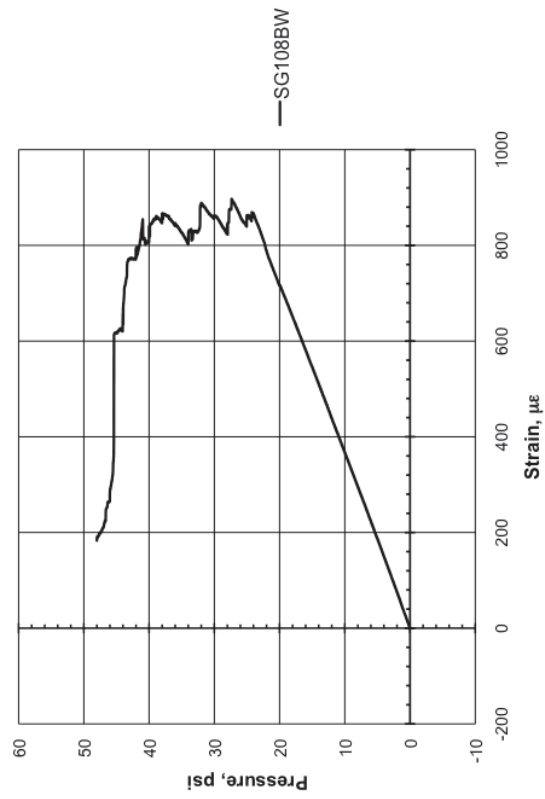


Figure E119. Test to failure, strain gage SG108BW.

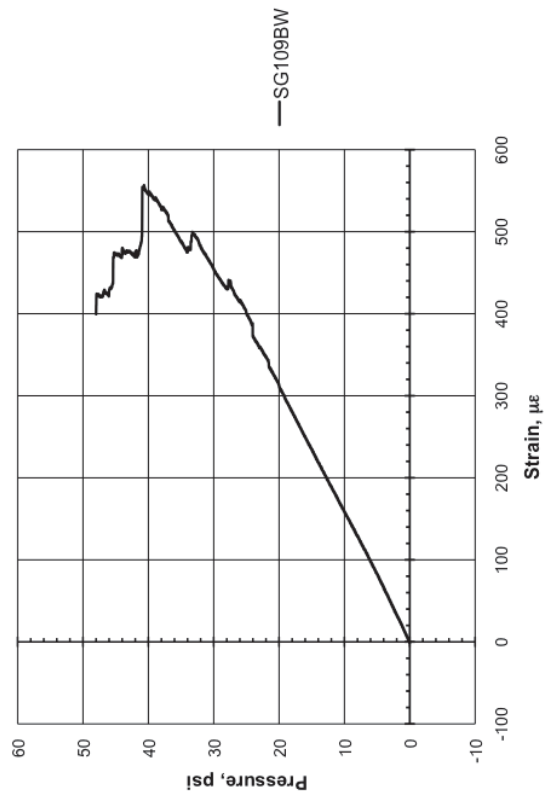


Figure E120. Test to failure, strain gage SG109BW.

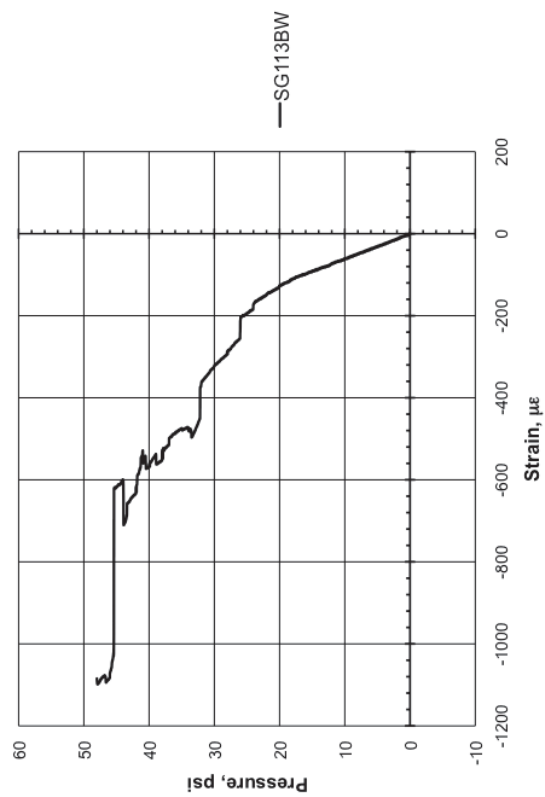


Figure E123. Test to failure, strain gage SG113BW.

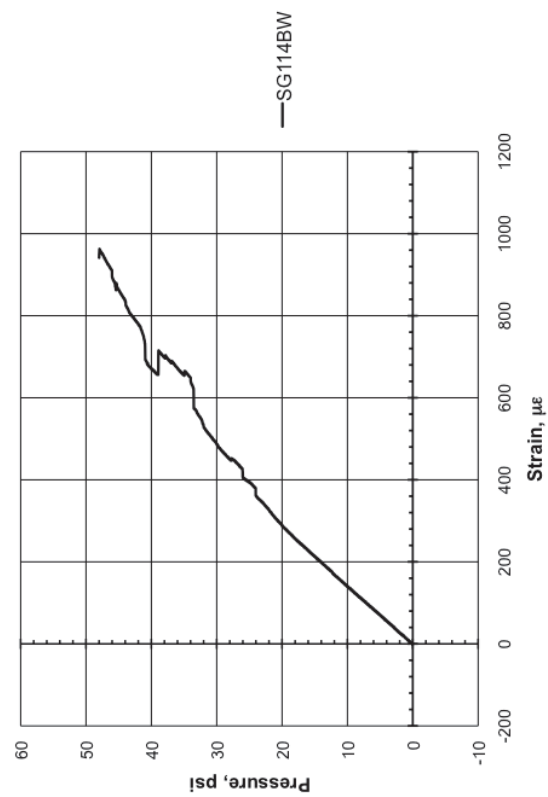


Figure E124. Test to failure, strain gage SG114BW.

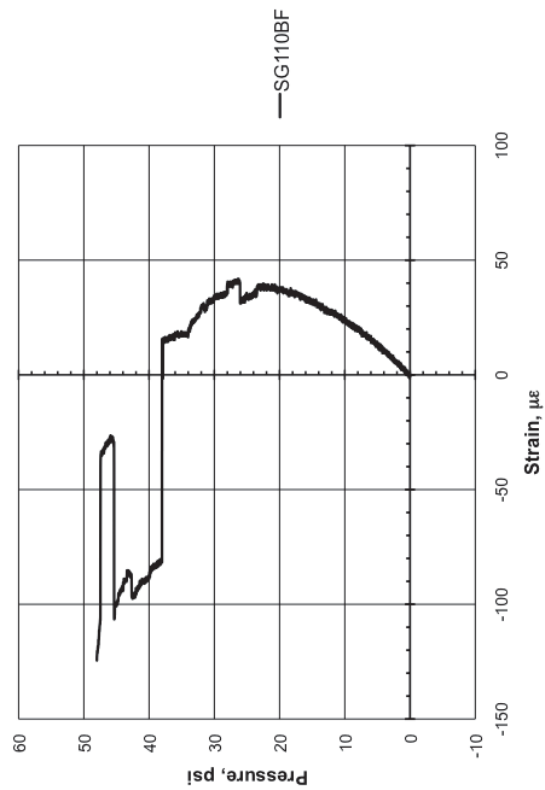


Figure E121. Test to failure, strain gage SG110BF.

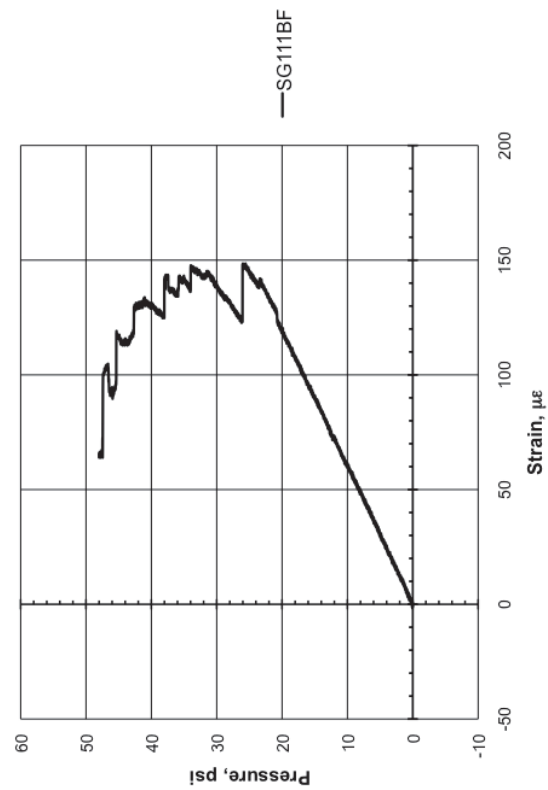


Figure E122. Test to failure, strain gage SG111BF.

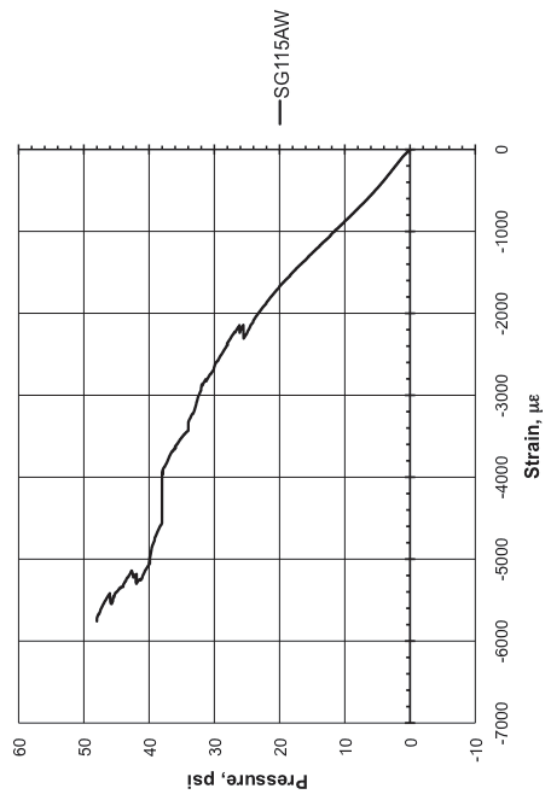


Figure E125. Test to failure, strain gage SG115AW.

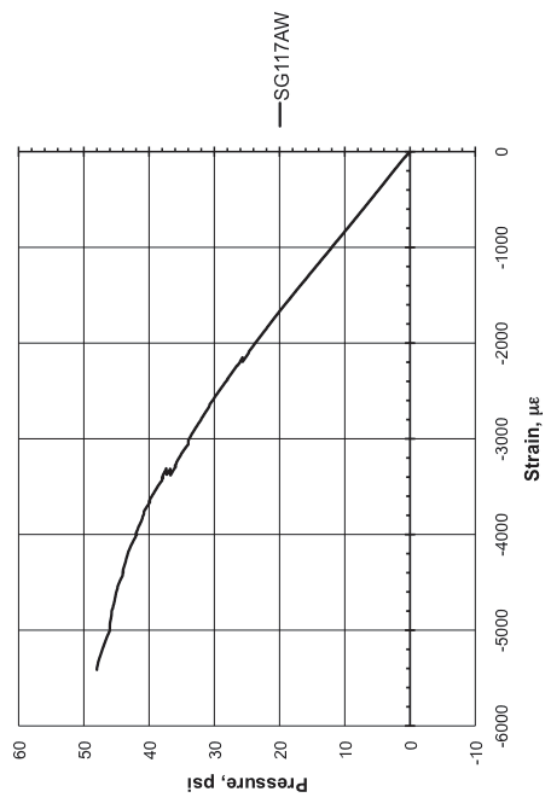


Figure E128. Test to failure, strain gage SG117AW.

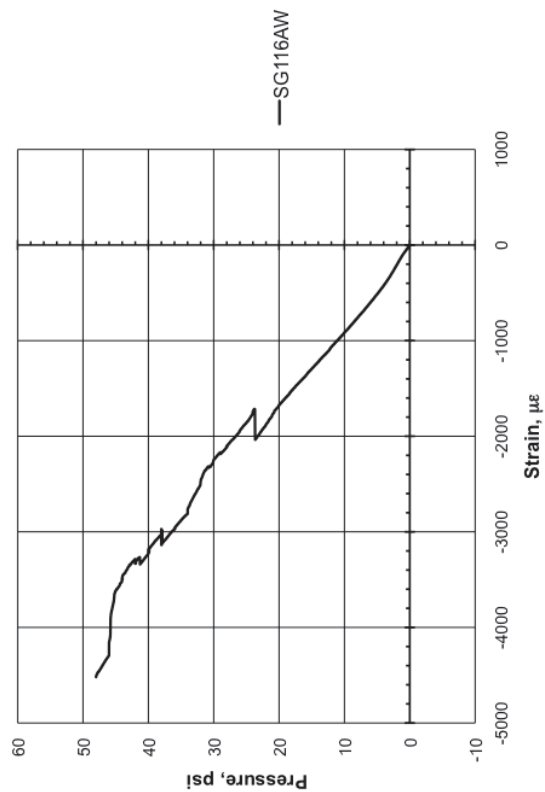


Figure E126. Test to failure, strain gage SG116AW.

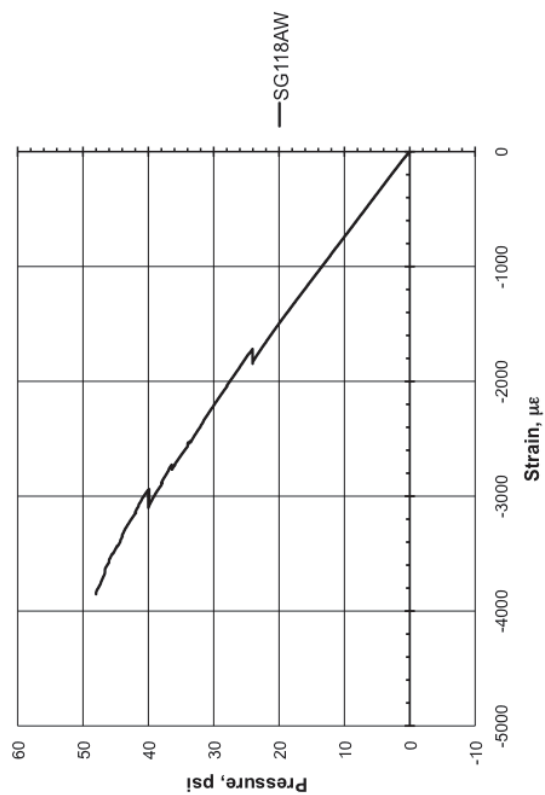


Figure E128. Test to failure, strain gage SG118AW.

| REPORT DOCUMENTATION PAGE                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |             |                      |                               |                                                                      | Form Approved<br>OMB No. 0704-0188                              |  |
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| <p>The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</p> <p><b>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</b></p>                                                                                                                                                                                                                                                                                                                                                                                                                                                           |             |                      |                               |                                                                      |                                                                 |  |
| 1. REPORT DATE (DD-MM-YYYY)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |             | 2. REPORT TYPE       |                               |                                                                      | 3. DATES COVERED (From - To)                                    |  |
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| 4. TITLE AND SUBTITLE<br><br>PRSEUS Pressure Cube Test Data and Response                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |             |                      |                               | 5a. CONTRACT NUMBER                                                  |                                                                 |  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |             |                      |                               | 5b. GRANT NUMBER                                                     |                                                                 |  |
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| 6. AUTHOR(S)<br><br>Lovejoy, Andrew E.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |             |                      |                               | 5d. PROJECT NUMBER                                                   |                                                                 |  |
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| 13. SUPPLEMENTARY NOTES<br><br>An Errata was added to this document January 2014.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |             |                      |                               |                                                                      |                                                                 |  |
| 14. ABSTRACT<br><br>NASA's Environmentally Responsible Aviation (ERA) Program is examining the hybrid wing body (HWB) aircraft, among others, in an effort to increase the fuel efficiency of commercial aircraft. The HWB design combines features of a flying wing with features of conventional transport aircraft, and has the advantage of simultaneously increasing both fuel efficiency and payload. Recent years have seen an increased focus on the structural performance of the HWB. The key structural challenge of a HWB airframe is the ability to create a cost and weight efficient, non-circular, pressurized shell. Conventional round fuselage sections react cabin pressure by hoop tension. However, the structural configuration of the HWB subjects the majority of the structural panels to bi-axial, in-plane loads in addition to the internal cabin pressure, which requires more thorough examination and analysis than conventional transport aircraft components having traditional and less complex load paths. To address this issue, while keeping structural weights low, extensive use of advanced composite materials is made. This report presents the test data and preliminary conclusions for a pressurized cube test article that utilizes Boeing's Pultruded Rod Stitched Efficient Unitized Structure (PRSEUS), and which is part of the building block approach used for HWB development. |             |                      |                               |                                                                      |                                                                 |  |
| 15. SUBJECT TERMS<br><br>PRSEUS; carbon-epoxy; composite; graphite; hybrid wing body; internal pressure; stitching                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |             |                      |                               |                                                                      |                                                                 |  |
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